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LANDAU ASSOCIATES, INC.

Final Extraction Well Plan

Phase II Remedial Design/Remedial Action
Colbert Landfill
Spokane, Washington

8/7/92

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Prepared for

Spokane County, Washington

Prepared by

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FORMS

LIST OF TABLES

1.0 INTRODUCTION

This document presents the Final Phase II Extraction Well Plan (Plan) for the Colbert Landfill Remedial Design/Remedial Action Project (Project). The purposes of the Phase II Interception/Extraction System are to intercept contaminated groundwater in the Colbert Landfill (Landfill) vicinity to minimize degradation of downgradient resources, and to provide source control near the Landfill. Additionally, data collected during Phase II extraction well construction will supplement Phase I hydrogeologic data and further the understanding of site hydrogeologic conditions.

Phase II Interception /Extraction System requirements are specified in Section V of the Project Consent Decree Scope of Work (U.S. District Court 1988). This Plan provides a description of the Project background and site conditions; the design for the Phase II (South and West) Interception Systems and the (East) Extraction System; procedures for Phase II extraction well construction; preliminary design for extraction well pumping, instrumentation, and controls; procedures for equipment decontamination; and disposal practices for soil cuttings and excess groundwater. Postconstruction operational procedures will be presented in the Project Operations and Maintenance Plan, which will be submitted concurrently with the Phase II plans and specifications.

This Plan was prepared by Landau Associates, Inc. (Landau Associates), Spokane County's engineering consultant for the Project. It is being submitted as part of the 60 percent design for the Phase II Remedial Action and constitutes 90 percent design of the Phase II extraction wells. Because well construction is dependent on site-specific conditions that cannot be assessed prior to boring advancement, final extraction well design (100 percent) will not be performed prior to construction. Instead, as-built well construction diagrams and boring logs will be submitted to EPA and Ecology subsequent to construction and will constitute 100 percent design. Ninety and 100 percent design for aspects of the Phase II Interception/Extraction System, other than the wells (i.e., pumping, instrumentation, and control systems), will be submitted as preliminary and final plans and specifications, respectively.

1.1 PROJECT BACKGROUND

The Colbert Landfill is an inactive, 40-acre, municipal solid waste landfill located approximately 15 miles north-northeast of Spokane, WA, and 2.5 miles north of Colbert, WA, as shown on the Regional Location Map (Figure 1-1). The Landfill operated from 1968 until 1986, when it became filled to capacity with municipal and commercial waste.

Groundwater in the vicinity of the Landfill is contaminated with chlorinated organic solvents. At least part of this contamination has been traced to spent solvents that were disposed of at the Landfill. Solvents were reportedly disposed of at an average rate of several hundred gallons per month for a number of years, and primarily consisted of 1,1,1-trichloroethane (TCA) and methylene chloride (MC). Other organic solvents were also detected in groundwater near the Landfill, including trichloroethylene (TCE), tetrachloroethylene (PCE), 1,1-dichloroethylene (DCE), and 1,1-dichloroethane (DCA). These six chlorinated organic solvents are referred to as the "Constituents of Concern."

In 1980, nearby residents complained to the Eastern Regional Office of Ecology about disposal practices at the Landfill. State and county officials, led by the Spokane County Utilities Department, initiated an investigation into complaints of groundwater contamination in the area by sampling nearby private wells. The results of this initial investigation indicated that some of these wells were contaminated with TCA. In August 1983, EPA placed the Colbert Landfill on its National Priorities List (NPL).

Several studies of the Landfill were conducted since 1980, including the 1987 Remedial Investigation/Feasibility Study (RI/FS; Golder Associates 1987a,b). The purpose of the RI/FS was to determine the nature and extent of contamination caused by the release of chemicals from the Landfill (or the Old Township Dump) and to evaluate potential remedies. The RI determined that the two primary aquifers in the Landfill vicinity (the Upper and Lower Sand/Gravel Aquifers), and a low-productivity aquifer to the east of the Landfill (Weathered Latah/Basalt Aquifer) are contaminated with some or all of the Constituents of Concern. The FS recommended a pump and treat remedy, to address this groundwater contamination.

EPA released its Colbert Landfill Record of Decision (ROD) for public comment in September 1987 (EPA 1987). The remedial action site (Site) is defined in the ROD as the area of potential impact surrounding and including the Landfill, as shown on Figure 1-1. Based on recommendations in the FS, the ROD provides for a performance-based remedial action, consisting of a groundwater pump and treat system. Project performance criteria for the Constituents of Concern are presented in the ROD (Performance Standards), and are shown in Table 1-1. These Performance Standards establish the level of treatment for extracted groundwater and define the maximum constituent concentrations that must be achieved for completion of the remedial action.

Although some flexibility is allowed in the remedial approach, the remedial action specified in the ROD provides for a groundwater extraction system, a treatment system, and a discharge system. The ROD subdivides the extraction system into the following three pumping systems:

- The South Interception System, which will consist of a series of extraction wells installed to intercept the contaminant plume in the Upper Sand/Gravel Aquifer south of the Landfill
- The West Interception System, which will consist of a series of extraction wells installed to intercept the contaminant plume in the Lower Sand/Gravel Aquifer west of the Landfill
- The East Extraction System, which will consist of extraction wells installed in the Lower Sand/Gravel and Latah/Basalt Aquifers near the Landfill for source control.

The ROD specifies that extracted groundwater will be treated using air stripping to reduce Constituents of Concern in groundwater to the Performance Standards. ROD-specified discharge options for treated water include the Little Spokane River, Deep Creek, and subsurface infiltration.

Subsequent to implementation of the ROD, a Consent Decree for the Colbert Landfill (U.S. District Court 1988) was negotiated between the EPA and Ecology (government plaintiffs), and Spokane County and Key Tronic Corporation (potentially responsible parties). By this action, the County agreed to implement the EPA-selected pump and treat remedy in accordance with the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) requirements and the State of Washington Hazardous Waste Cleanup Act (codified as Chapter 70.105B RCW).

A scope of work (SOW) to address groundwater contamination emanating from the Landfill is presented in Appendix B of the Consent Decree (U.S. District Court 1988). The SOW specifies the bases for design, design criteria, and criteria for adjustment and modification of the pump and treat system if the performance criteria are exceeded during operation of the remedial action. Because of the difficulties in accurately quantifying MC and DCE at their Performance Standard concentrations, alternative criteria (Evaluation Criteria) are developed in the SOW for assessing performance of Project interception, treatment, and discharge systems, and are presented in Table 1-1.

It was recognized during development of the Consent Decree that available data were inadequate to design the selected remedial action. Consequently, the Project is being implemented in phases. Phase I activities were completed in 1991 and included a number of activities. Thirty groundwater monitoring wells were constructed at 19 locations for additional hydrogeologic and contaminant distribution characterization. Four pilot extraction wells were constructed for aquifer performance (pumping) tests and as source wells for groundwater treatability studies. A pilot air stripping tower was constructed to treat extracted groundwater from pumping tests and for groundwater treatability studies. A discharge system, including piping and outfalls, was constructed to convey water from the pilot extraction wells to the pilot treatment facility and from the treatment facility to the effluent discharge locations. An onsite meteorological station was also constructed to collect meteorological data. The locations of groundwater monitoring wells and pilot extraction wells constructed during Phase I are shown on Figure 1-2.

Phase I activities were completed in July 1991, and Phase I results are provided in the Phase I Engineering Report (Landau Associates 1991). A conceptual plan for the Phase II remedial action was presented in the Phase I Engineering Report, based on the results of Phase I activities, and shown on Figure 1-3. Phase II design, including the interception and extraction system design presented in this Plan, are largely based on the results of Phase I.

1.2 SITE CONDITIONS

The Landfill is located on a plateau that is bounded on the west by a steep slope descending toward the Little Spokane River and on the east by low granite and basalt hills. Surface drainage is to the west, toward the Little Spokane River. The climate is characteristic of eastern Washington, with temperatures ranging from typical average summer highs of 83°F to average winter lows of 23°F. The relatively low annual precipitation of approximately 17 inches falls mainly during the winter months of November through February (NOAA 1985).

1.2.1 Hydrogeologic Conditions

The geology of the Landfill area consists of a series of glacially and fluvially derived materials deposited on an eroded landscape of clays, basaltic lava flows, and granitic bedrock. The primary stratigraphic units (layers), from youngest to oldest (i.e., from the top down), are:

Unit A.	Upper Sand/Gravel Unit
Unit B.	Lacustrine Unit
Unit C.	Lower Sand/Gravel Unit
Unit D_1	Weathered Latah Subunit
Unit D.	Latah Formation
Unit E.	Basalt Unit
Unit F.	Granite Unit.

A generalized east-west profile of these units is shown on Figure 1-4. Detailed geologic cross sections are presented on Figures ER-4.2 through ER-4.9 of the Phase I Engineering Report (Landau Associates 1991).

The hydrogeologic system in the Landfill vicinity can be characterized as containing four aquifers (two primary and two secondary) and three aquitards:

- The Upper Sand/Gravel Unit (Unit A) forms the Upper Sand/Gravel Aquifer when underlain by the Lacustrine Unit (Unit B), and is considered a primary aquifer.

- The Lacustrine Unit (Unit B) is the low-permeability unit that separates the Upper and Lower Sand/Gravel Units and is referred to as the Lacustrine Aquitard. The Lacustrine Aquitard contains water-bearing sand layers and, based on water elevation data, some of the shallow sand layers appear to be in direct hydraulic connection with the Upper Sand/Gravel Aquifer.
- The Lower Sand/Gravel Unit (Unit C) forms the Lower Sand/Gravel Aquifer, which is the second primary aquifer and the regional aquifer for the Site.
- The Latah Formation (Unit D) and the Weathered Latah Subunit (Unit D_1) serve as the aquitard underlying the Lower Sand/Gravel Aquifer at most locations and, in combination, are referred to as the Latah Aquitard. However, some low-yield private wells are installed in the Latah Aquitard to the east of the Landfill where the Upper and Lower Sand/Gravel Aquifers are not present.
- The Basalt Unit (Unit E) forms a secondary aquifer interbedded with the Latah Aquitard and is referred to as the Basalt Aquifer.
- The Granite Unit (Unit F) serves as the lower boundary (aquitard) to the regional flow system, although some low-productivity wells are installed in the upper portion of this unit.
- The Fluvial Unit associated with the Little Spokane River forms the Fluvial (secondary) Aquifer. The Fluvial Aquifer may be in direct hydraulic connection with the Lower Sand/Gravel Aquifer, but piezometric and contaminant migration data [as discussed in the Phase I Engineering Report (Landau Associates 1991)] suggest that it be treated as an independent hydrogeologic unit for the purposes of this Project.

Units C, D, E, and F are collectively referred to as the "Lower Aquifers" for evaluating regional groundwater flow and contaminant distribution, although the Lower Sand/Gravel Aquifer (Unit C) appears to be the only one of these units capable of sustained yield at significant discharge rates.

The Upper Sand/Gravel Aquifer is unconfined, with a depth to water about 90 ft below ground surface in the Landfill vicinity. The thickness of the Upper Sand/Gravel Aquifer varies from about 8-20 ft along its north-south trending centerline, and decreases as it extends toward the western bluff and eastern hills. Upper Sand/Gravel Aquifer groundwater flow is predominantly toward the south, with velocities ranging from 5-7 ft/day (Landau Associates 1991). A groundwater elevation contour map for the Upper Sand/Gravel Aquifer is shown on Figure 1-5.

The Lower Sand/Gravel Aquifer is generally confined west of the Landfill and unconfined from the west Landfill boundary to the east. The potentiometric surface of the Lower Sand/Gravel Aquifer is about 180 ft below ground surface, and its saturated thickness varies from 0 ft east of the Landfill to over 200 ft near U.S. Highway 2. Groundwater in the Lower Sand/Gravel Aquifer flows predominantly towards the west at velocities ranging from 0.3 to 0.6 ft/day (Landau Associates 1991). However, a lobe of low permeability Latah Aquitard extends to the west into the Lower Sand/Gravel Aquifer. This lobe forms an east-west trending groundwater divide beneath the south Landfill boundary, and causes constituents that enter the Lower Sand/Gravel Aquifer from the Landfill vicinity to migrate in separate (northern and southern) flow regimes.

East of the Lower Sand/Gravel Aquifer, groundwater flow occurs primarily as perched groundwater at the Lower Sand/Gravel Unit interface with the underlying Latah Aquitard and within the Basalt (secondary) Aquifer, although some domestic wells are screened within the Latah and Granite Aquitards. Pumping test data and other hydrogeologic information indicate that groundwater extraction east of the Lower Sand/Gravel Aquifer is impracticable because of limited aquifer yield, and may exacerbate the spread of contamination in this area (Landau Associates 1991). A groundwater elevation contour map for the combined Lower Aquifers is shown on Figure 1-6.

A number of hydrogeologic boundary conditions converge in the immediate vicinity of the Landfill:

- The Lacustrine Aquitard pinches out, eliminating the hydraulic separation between the Upper and Lower Sand/Gravel Aquifers
- The Lower Sand/Gravel Unit transitions from unsaturated (to the east) to the primary regional aquifer (to the west)
- A lobe of the Latah Aquitard extends (westerly) into the Lower Sand/Gravel Aquifer, creating an east/west trending groundwater divide near the south edge of the Landfill.

These converging boundary conditions control migration of groundwater (and contaminants) from the Landfill vicinity into and within the Lower Aquifers. Groundwater (from beneath the Landfill) enters the unsaturated Lower Sand/Gravel Unit either by lateral flow over the eastern edge of the Lacustrine Aquitard or, possibly, by direct infiltration through discontinuities in the Lacustrine Aquitard. Groundwater migrates vertically within the Lower Sand/Gravel Unit until contacting the upper surface of the Latah Aquitard. Groundwater then flows (as perched groundwater) along the Lower Sand/Gravel Unit and Latah Aquitard contact until it enters the Lower Sand/Gravel Aquifer (Northern or Southern) Flow Regime. A conceptual model of these groundwater flow characteristics is shown on Figure 1-7.

1.2.2 Constituent Distribution

The Upper Sand/Gravel Aquifer, Fluvial Aquifer, and shallow sand interbeds of the Lacustrine Aquitard are collectively referred to as the Upper Aquifers for assessing the distribution of Constituents of Concern in groundwater. The Lower Sand/Gravel Aquifer, Basalt Aquifer, Latah Aquitard, and Granite Aquitard are similarly referred to as the Lower Aquifers for constituent distribution evaluation. Figures 1-8 and 1-9 show the distribution of the Constituents of Concern for the Upper and Lower Aquifers, respectively. These figures are based on a composite of groundwater quality data collected through 1991, and represent the areal extent over which one or more of the Constituents of Concern were detected and the area over which one or more of the Constituents of Concern exceed the Performance Standards.

1.3 PROJECT OBJECTIVES

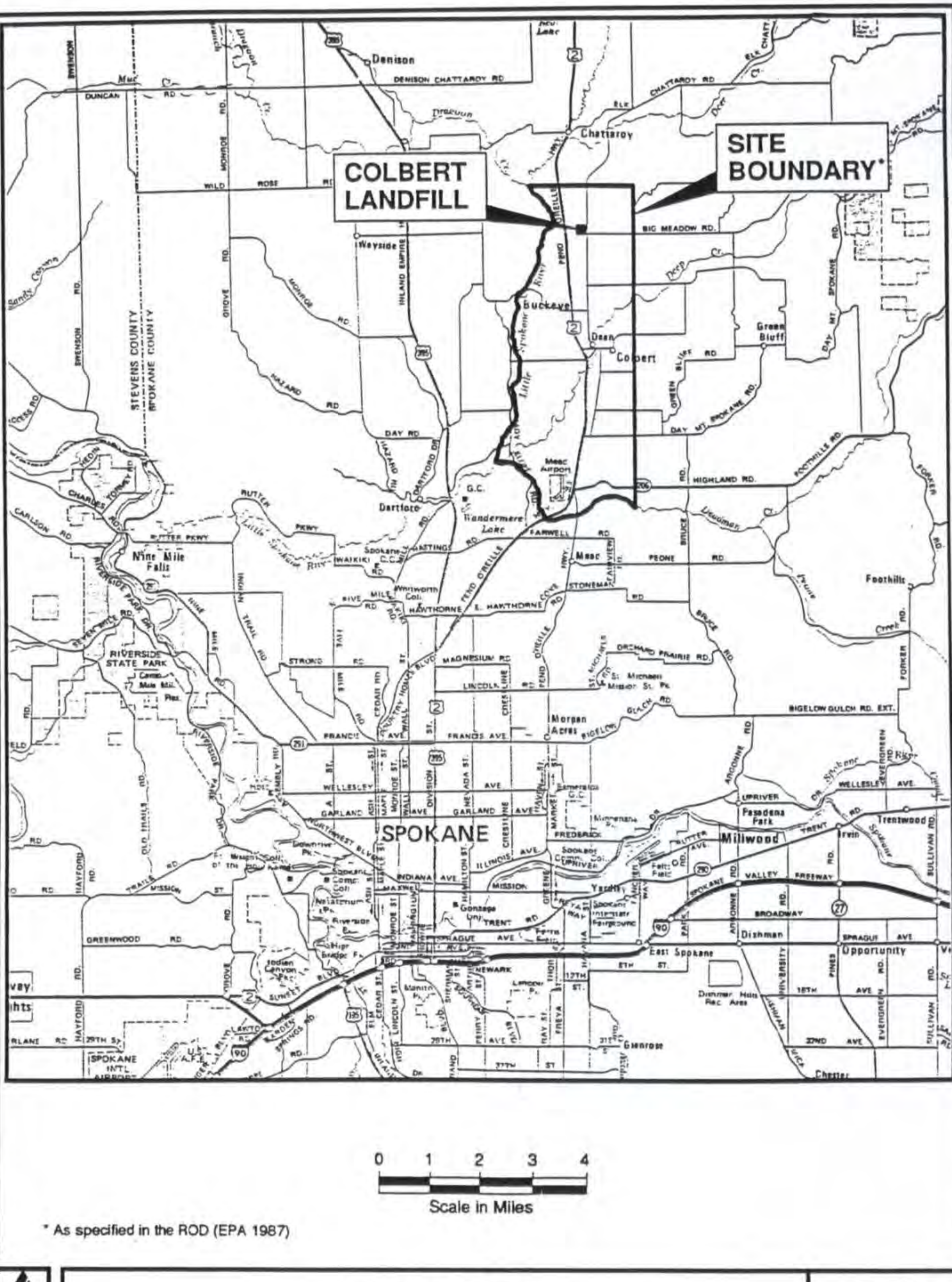
The Project objectives are to: 1) implement aquifer performance and treatability studies to develop design parameters for the final (Phase II) remedial action; 2) perform supplemental characterization (to the RI) of hydrogeologic conditions and the extent of groundwater contamination in the vicinity of the South, West, and East Interception/Extraction Systems; 3) design the final remedial action; and 4) construct the final remedial action and operate the system until the requirements of the Consent Decree are fulfilled.

Objectives 1 and 2 were achieved during Phase I, as documented in the Phase I Engineering Report (Landau Associates 1991). Objective 3 is being implemented and will be documented in Phase II work plans and plans and specifications. Phase II 30 percent design was presented in the Preliminary Phase II work plans. Sixty percent design will be presented in the final Phase II work plans, including this Plan, the Groundwater Monitoring Plan, and the Treatment and Discharge Plan. Ninety percent and 100 percent design will be submitted as preliminary and final plans and specifications, respectively. Objective 4 will be achieved following EPA and Ecology approval of the Phase II design documents.

1.4 PHASE II DESIGN SCHEDULE

The Phase II design process was initially anticipated to require about 15 months. EPA and Ecology review periods for the Preliminary Phase II work plans exceeded the planned review period by up to 1 month, extending the design schedule to 16 months. Additionally, National Pollutant Discharge Elimination System (NPDES) issues raised by Ecology may impact the design (and viability) of the selected remedial action, and must be resolved prior to completing remedial design. Although NPDES issues are currently being addressed, their impact on the Phase II design schedule cannot be determined at this time. The estimated Phase II design schedule is shown on Figure 1-10.

Several EPA and Ecology design reviews are incorporated into Phase II design. The actual time required for Phase II design is dependent on timely EPA and Ecology review and resolution of the NPDES issues. The estimated submittal dates shown on Figure 1-10 do not include delays that may result from the time required to resolve the NPDES issues, and are subject to modification once NPDES issues are resolved or if future EPA and Ecology review comments and approvals are not provided within the indicated period.



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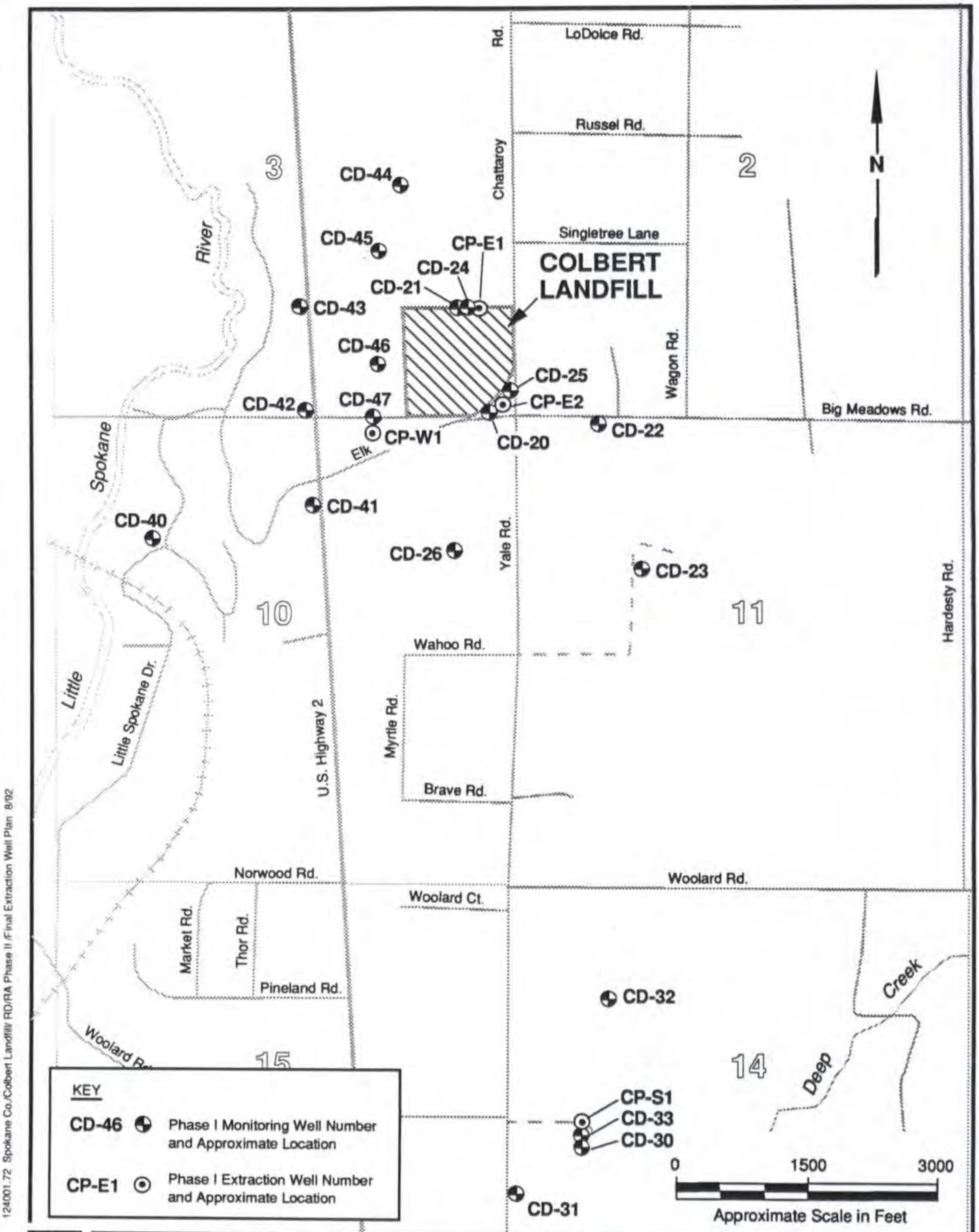
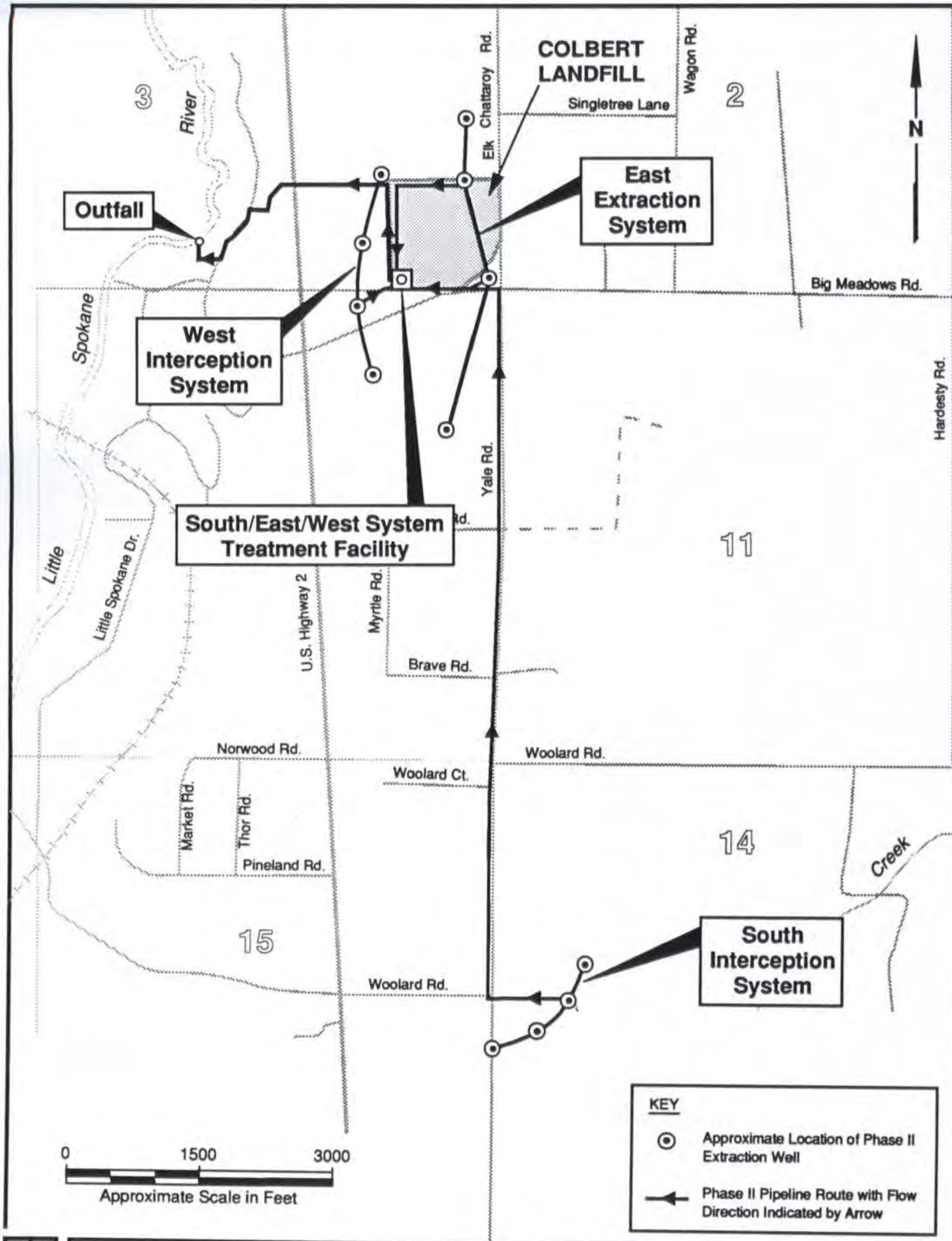
Regional Location Map

Figure 1-1



Location of Phase I Monitoring and Extraction Wells

Figure 1-2



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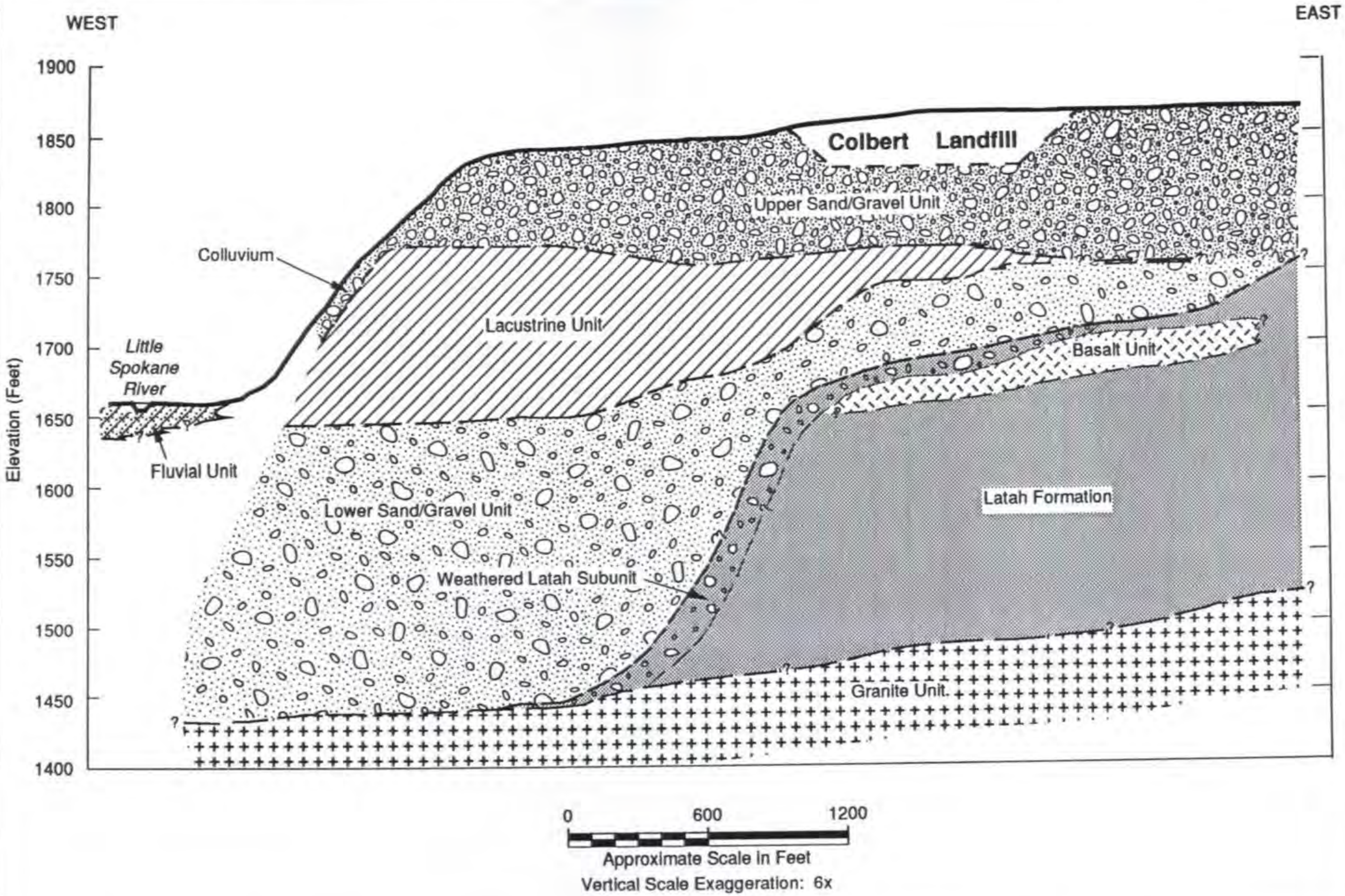
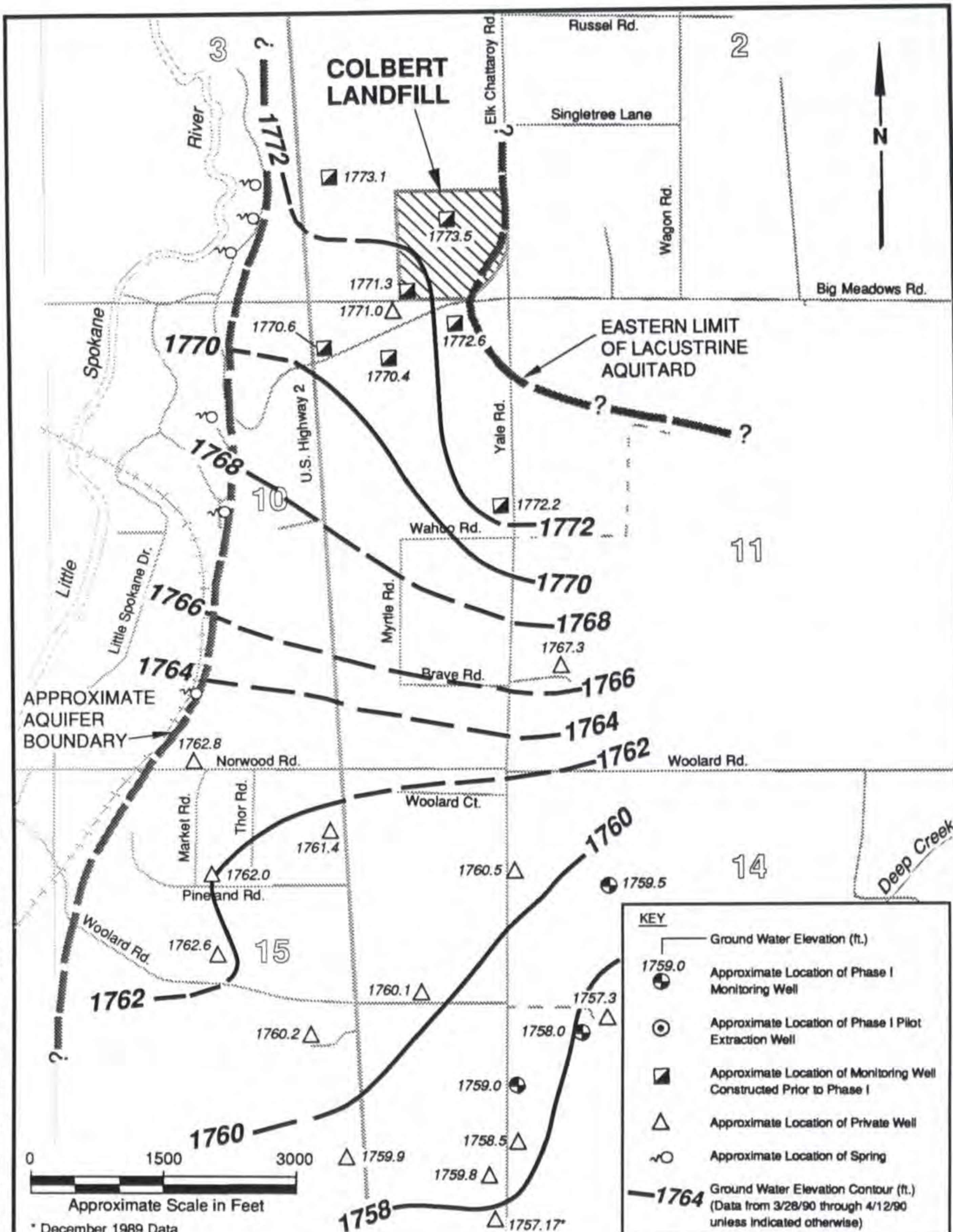
Phase II Conceptual Design

Figure 1-3



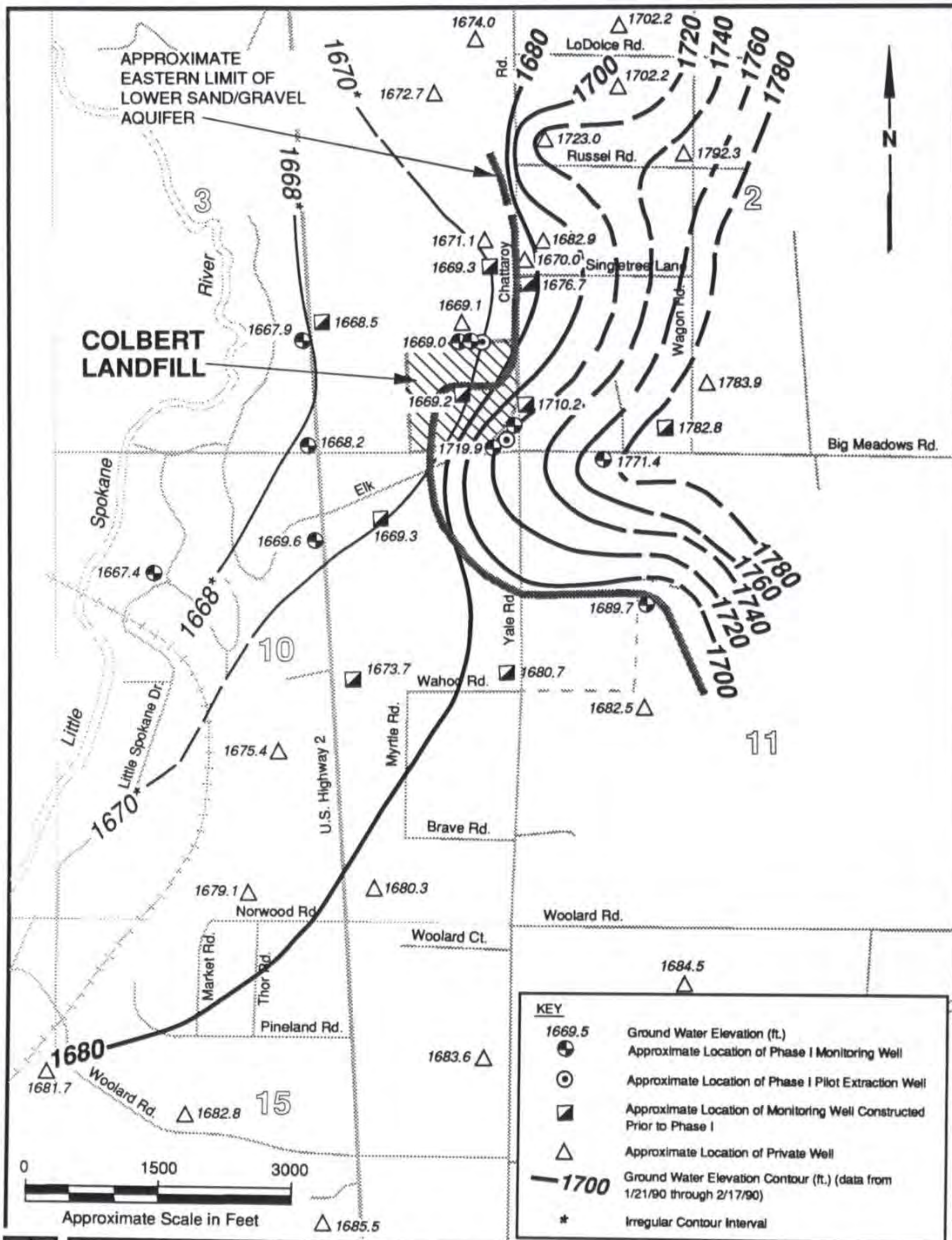
Generalized East-West Geologic Profile

Figure 1-4



Upper Sand/Gravel Aquifer
Groundwater Elevation Contours

Figure 1-5



Lower Aquifers
Groundwater Elevation Contours

Figure 1-6

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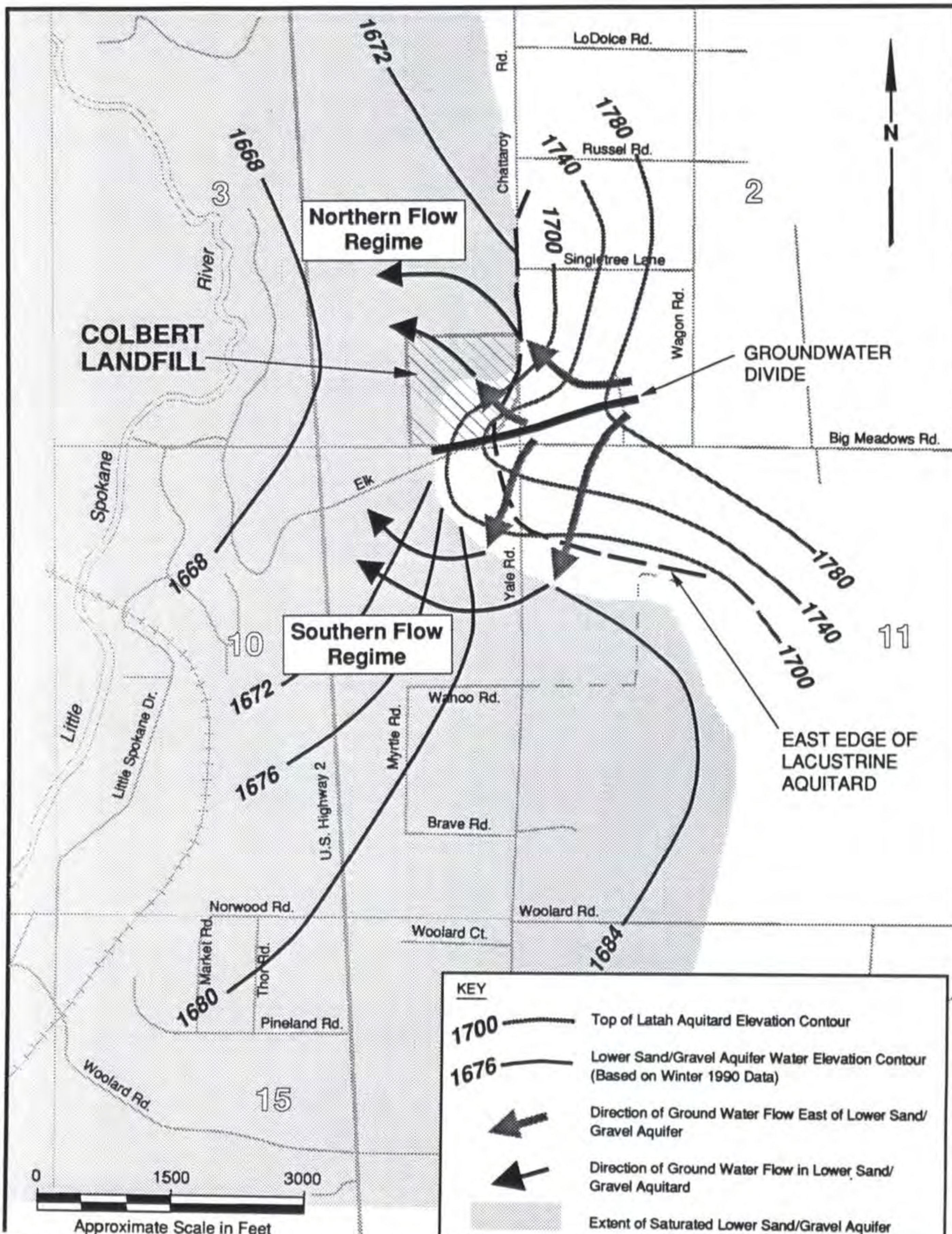
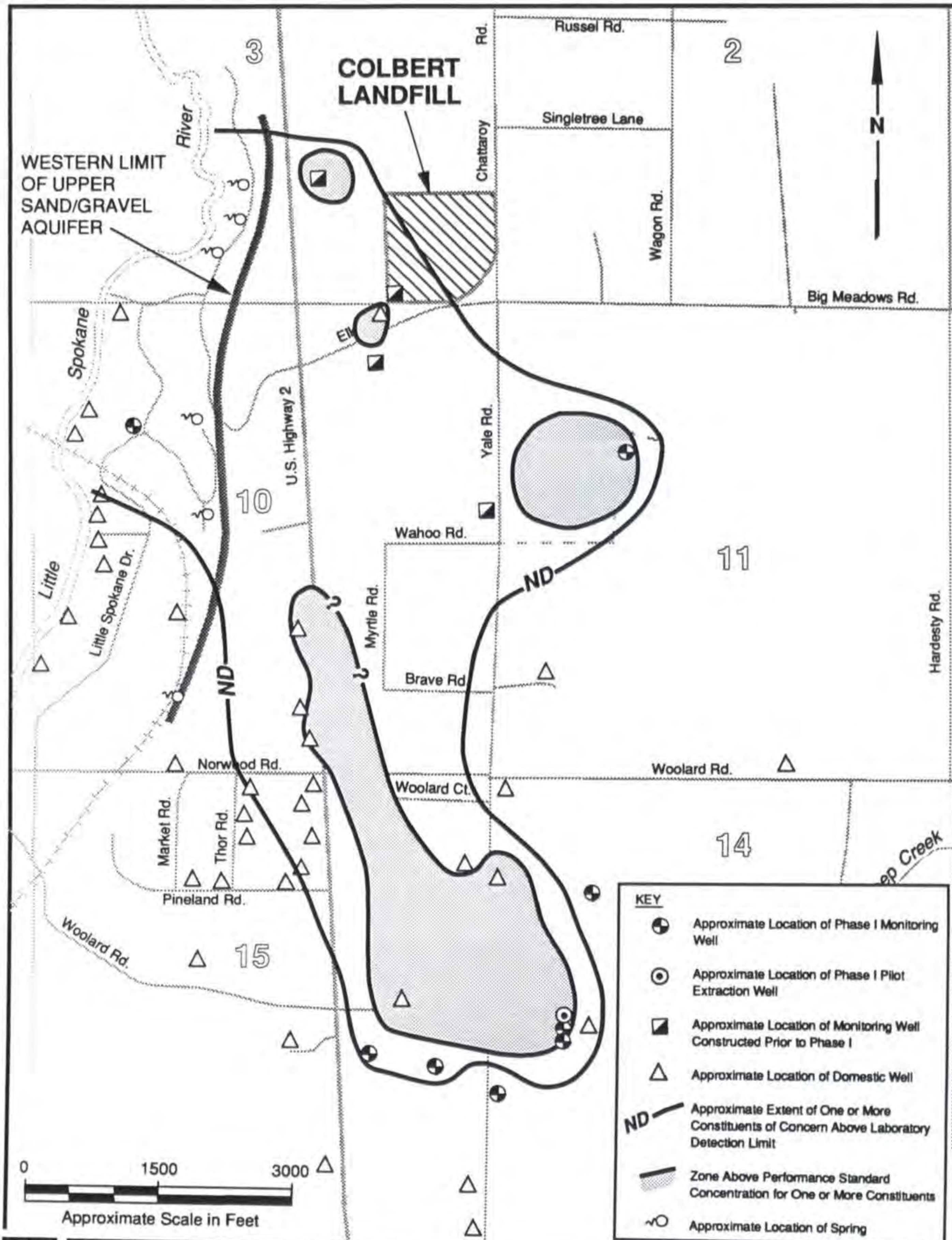


Conceptual Model
Lower Aquifers Groundwater Flow

Figure 1-7



Upper Aquifers
Approximate Extent of Constituents of Concern

Figure 1-8

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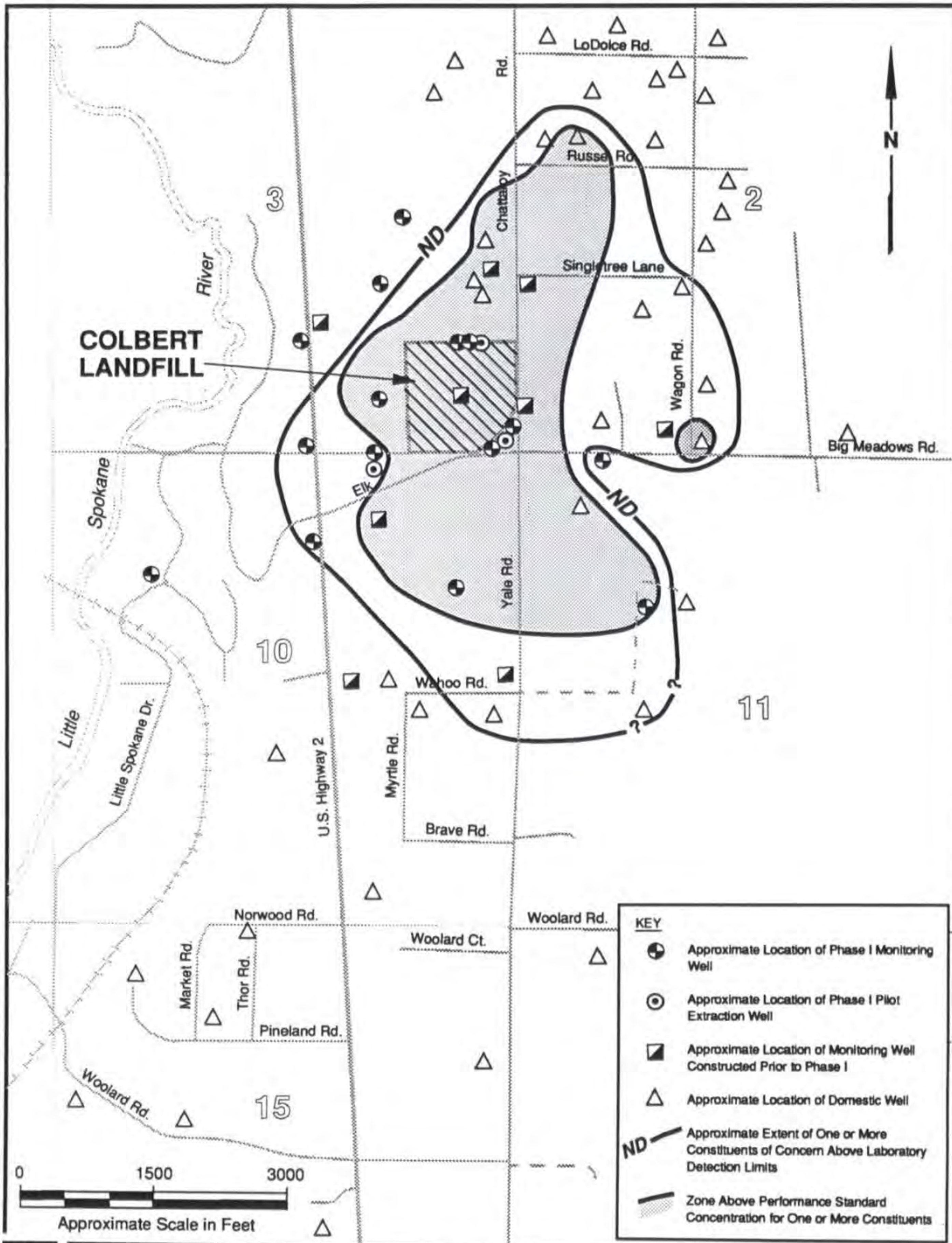

Lower Aquifers
Approximate Extent of Constituents of Concern

Figure 1-9

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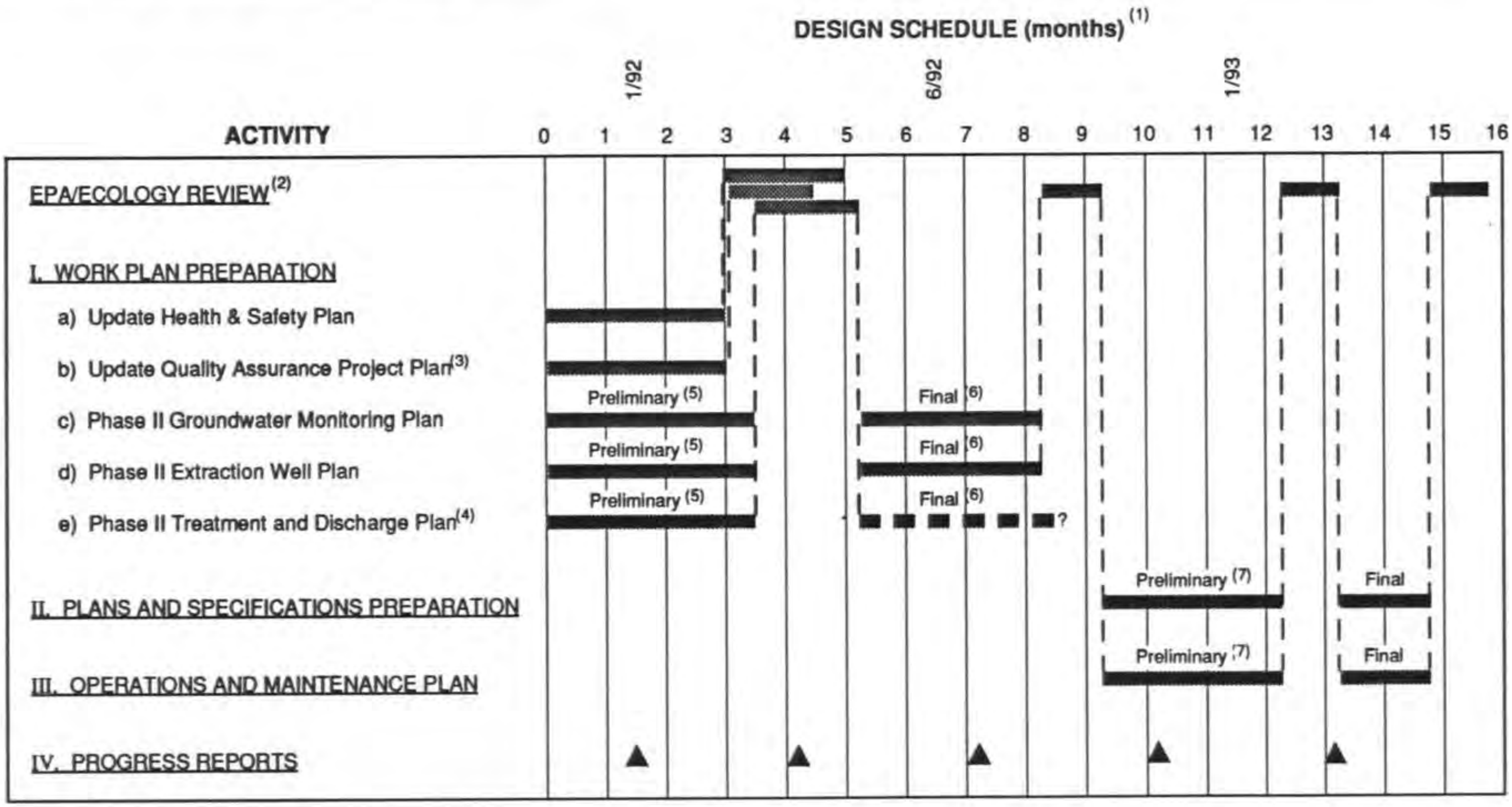


NOTES

1. 1/92 ← Estimated Date. Actual dates for submittals may be modified if EPA/Ecology reviews are not completed within the allocated period.
   1 2 ← Time in months since EPA/Ecology approval to proceed with Phase II design.
2. Actual EPA/Ecology preliminary work plan review period shown. One month review period was scheduled.
3. The QAPjP may require further revision, depending on NPDES monitoring requirements, and will not be finalized until NPDES issues are resolved.
4. The Treatment and Discharge Plan cannot be finalized until NPDES issues are resolved, so the submittal date for this plan is undetermined.
5. Represents 30% Design Submittal.
6. Represents 60% Design Submittal.
7. Represents 90% Design Submittal. Actual submittal date is dependent on resolution of the NPDES issues, and completion of the Phase II Treatment and Discharge Plan.

Phase II Design
Estimated Schedule

Figure 1-10

TABLE 1-1[a]

PROJECT PERFORMANCE CRITERIA[b]

Constituent of Concern	Performance Standards	Evaluation Criteria
1,1,1-Trichloroethane (TCA)	200	200
1,1-Dichloroethylene (DCE)	7	7
1,1-Dichloroethane (DCA)	4050	4050
Trichloroethylene (TCE)	5	5
Tetrachloroethylene (PCE)	0.7	7
Methylene Chloride (MC)	2.5	25

(a) From Consent Decree Scope of Work.

(b) All concentreations in parts per billion (ppb).

2.0 INTERCEPTION/EXTRACTION SYSTEM DESIGN

This section describes the design for the Phase II South and West Interception and East Extraction Systems. Interception system design includes determining the spacing and discharge rates of extraction wells required to create an effective hydraulic barrier to groundwater contaminant migration, designing individual extraction wells (screen length, well depth, and well diameter), and designing the pumping, instrumentation, and control systems for operation of the system. Extraction system design includes selecting the location and discharge rates of extraction wells to provide effective groundwater extraction for source control, designing individual extraction wells, and designing the pumping, instrumentation, and control systems for system operation. Conveyance of extracted groundwater from the well to the treatment facility is often part of interception system design, but is included in the Preliminary Phase II Treatment and Discharge Plan (Landau Associates 1992a) for this Project.

2.1 BASIS FOR DESIGN

Section V of the SOW (U.S. District Court 1988) specified the basis for design for the South and West Interception Systems, and the East Extraction System. The basis for design of the South Interception System (per Section V.A. of the SOW) is that the average concentrations of the Constituents of Concern in the Upper Sand/Gravel Aquifer downgradient of the interception system are predicted to be no greater than 15 percent of the Performance Standards, based on capture zone analyses. It is identified in Section V.C. of the SOW that a higher level of protection is appropriate for that portion of the Lower Sand/Gravel Aquifer downgradient of the West Interception System within the zone of capture of existing supply wells than is appropriate for that portion of the aquifer downgradient of the West Interception System where contaminants can migrate directly to the Little Spokane River without impacting existing supply wells. Consequently, the basis for design of that portion of the West Interception System that intercepts groundwater migrating into the capture zone(s) of existing downgradient supply wells is the same as for the South Interception System (predicted downgradient concentrations no greater than 15 percent of the Performance Standards). However, the basis for design of the remainder of the West Interception System is that the average concentrations of the Constituents of Concern in the Lower Sand/Gravel Aquifer downgradient of the West Interception System are predicted to be no greater than 50 percent of the Performance Standards.

Section V of the SOW provides additional design requirements for the South and West Interception Systems. These design requirements include:

- The interception systems will be designed utilizing capture zone analysis to achieve overlapping cones of depression
- The interception systems will have sufficient pumping capability to intercept the plume to the extent required to meet the basis for design (previously described)
- Extraction wells will be installed until the groundwater at the outermost limits of the interception system is below the adjustment control criteria (65 percent of the Evaluation Criteria).

Because the East Extraction System is intended for source control near the Landfill and not as an interception system, the basis for design and the design requirements for the South and West Interception Systems do not apply. Section V.B. of the SOW specifies that the East Extraction System will include six or more extraction wells to the north and east of the Landfill. As will be discussed in a subsequent section of this Plan, hydrogeologic conditions characterized subsequent to development of the SOW (during Phase I) indicate the location and initial number of East Extraction wells should vary from that described in the SOW.

Section V of the SOW is provided in Appendix A of this Plan.

2.2 DESIGN METHOD

Various analytical and numerical methods are available for designing a groundwater interception system. Analytical methods provide the least complex approach to interception system design, and are appropriate for relatively homogeneous, uniform aquifers without complex boundary conditions. However, most analytical models are subject to a number of simplifying assumptions that limit their usefulness for more complex hydrogeologic systems. These simplifying assumptions include:

- The aquifer is homogeneous, isotropic, and of infinite areal extent (i.e., no boundary conditions)
- The aquifer is of uniform thickness
- The aquifer exhibits a uniform flow field.

Because of the complex hydrogeologic conditions present in the Landfill vicinity [see Sections 4.1 and 4.2 of the Phase I Engineering Report (Landau Associates 1991) for a detailed discussion of hydrogeologic conditions], analytical analyses were considered inadequate for South and West Interception System design. MODFLOW (McDonald and Harbaugh 1988), a finite-difference numerical groundwater flow model developed by the U.S. Geological Survey, was utilized to develop (separate) groundwater flow models for the Upper and Lower Sand/Gravel Aquifers for interception and extraction system design.

2.2.1 Groundwater Flow Model

Aquifer hydrogeologic properties and boundary conditions for the models were selected based on the results of the Phase I investigation, as presented in the Phase I Engineering Report (Landau Associates 1991). Upper and lower bound hydraulic conductivity estimates were developed during Phase I for both the Upper and Lower Sand/Gravel Aquifers. Upper and lower bound model flow scenarios were developed, based on upper and lower bound hydraulic conductivities, for both aquifer models so that upper and lower bound pumping rates could be estimated for the interception/extraction systems. The range in hydraulic conductivity used for upper and lower bound model flow scenarios is provided in Table 2-1.

The groundwater flow models were calibrated to measured piezometric heads in their respective aquifers, such that the residual head differences (between measured and predicted heads) in the vicinity of the proposed interception systems were within acceptable bounds. Also, groundwater flux calculated using Phase I estimates of aquifer cross-section area, hydraulic conductivity, and hydraulic gradient was compared to model-generated fluxes for consistency.

The model extent and boundary conditions for the Upper and Lower Sand/Gravel Aquifers are shown on Figures 2-1 and 2-2, respectively; an explanation of model boundary condition terminology is provided in Appendix B. Steady-state (nonpumping) groundwater elevations for the Upper and Lower Sand/Gravel Aquifer groundwater flow models are shown on Figures 2-3 and 2-4, respectively. A more detailed discussion of groundwater flow model development and calibration is provided in Appendix B.

2.2.2 Extraction Well Locations

Following development of the steady-state (nonpumping) groundwater flow models, extraction well locations were selected for the South and West Interception Systems and the East Extraction System. Extraction well locations and spacings were selected such that the South and West Interception Systems meet the requirements of the SOW (as described in Section 2.1). Because of the potential variability in aquifer conditions, the interception systems were designed to meet the SOW requirements for both upper and lower bound flow conditions, with additional system capacity to accommodate expansion beyond the model-predicted flow rates.

Because of the limited saturated thickness of the Upper Sand/Gravel Aquifer, South Interception System well spacings were selected based on available drawdown (versus estimated drawdown), using the lower bound flow scenario. Alternatively, maximum estimated pumping rates, which are used to size extraction well pumps and (minimum) well diameters, are based on the upper bound flow scenarios.

The Lower Sand/Gravel Aquifer is highly transmissive, has a relatively flat gradient in the Landfill vicinity, and has a significant saturated thickness (greater than 100 ft) along the proposed West Interception System alignment (Landau Associates 1991). As a result, extraction wells in the Lower Sand/Gravel Aquifer can create large capture zones with minimal drawdown. Therefore, available drawdown is not a significant concern for West Interception System design. West Interception System extraction well locations were selected to provide a flexible system, capable of responding to potential variations in hydrogeologic conditions and potential changes in system needs as the remedial action progresses.

The SOW specifies six extraction wells for the East Extraction System, consisting of three wells to the north of the Landfill (in the Lower Sand/Gravel Aquifer) and three wells to the east of the Landfill (in the Latah Aquitard and Basalt Aquifer). However, data collected during Phase I indicate the East Extraction System should vary from that described in the SOW. The Lower Sand/Gravel Aquifer is sufficiently transmissive to provide source control with two (rather than three) wells to the north of the Landfill. Phase I contaminant distribution data indicate that an additional source control well south of the Landfill (in the Lower Sand/Gravel Aquifer) is also advisable. Data and analyses developed during Phase I indicate that a sufficiently transmissive aquifer is not present east of the Landfill to provide effective source control, and operation of extraction wells east of the Landfill may induce contaminant migration in this direction [see Section 5.2 of the Phase I Engineering Report (Landau Associates 1991)]. Thus, no extraction wells are proposed for installation east of the Landfill. However, existing Phase I Extraction Well CP-E2 (located near the southeast corner of the Landfill) will be included in the East Extraction System.

Because of the hydrogeologic conditions identified in the preceding paragraph, only four extraction wells (existing wells CP-E1 and CP-E2, and two new Lower Sand/Gravel Aquifer wells) are proposed for the East Extraction System(instead of the six extraction wells specified in the SOW). It is proposed that the two additional extraction wells specified in the SOW be retained for potential installation subsequent to Phase II startup, if Phase II operational data identify suitable locations. The location and timing for construction of these additional wells (if needed) will be at the discretion of EPA and Ecology.

Because of the highly transmissive nature of the Lower Sand/Gravel Aquifer, East Extraction System wells screened in the Lower Sand/Gravel Aquifer will interact with the West Interception System. Consequently, East Extraction System wells (screened in the Lower Sand/Gravel Aquifer) are included in capture zone analysis for the West Interception System.

An extraction well number program was developed for Phase I pilot extraction wells, and will be utilized for Phase II. Extraction wells will be numbered as follows:

- South Interception System: CP-S's (S1, S2, etc.)
- West Interception System: CP-W's
- East Extraction System: CP-E's

The proposed and existing extraction well locations for South and West Interception and East Extraction Systems are shown on Figure 2-5.

2.2.3 Capture Zone Analysis

Extraction well capture zones cannot be determined directly from the groundwater flow model. Instead, PATH3D (Papadopoulos & Associates 1991), a groundwater flow path and travel-time simulation program, was used in conjunction with the MODFLOW numerical model. PATH3D is an analytical model that tracks the migration of a particle through a groundwater flow field, and is specifically designed to work with MODFLOW.

A capture zone for an extraction well or interception system can be estimated by releasing a series of particles upgradient of the well (or wells), perpendicular to the direction of groundwater flow, and observing the zone within which particles are captured by the well or wells. For an interception system, the well spacing and/or pumping rate must be adjusted until the zone of capture for the system is adequate, and particles are not escaping the system between adjacent extraction wells. For aquifers with limited available drawdown (such as the Upper Sand/Gravel Aquifer), available drawdown must be compared to predicted drawdown to verify that the well is capable of sustaining the required discharge rate.

Five extraction wells are required for the South Interception System to achieve adequate plume capture, based on the capture zone analysis previously described. Model-predicted system pumping rates vary from about 250 gpm to 300 gpm for the lower bound and upper bound flow scenarios, respectively. The capture zone for the South Interception System, based on the upper bound flow scenario (the capture zones for the upper and lower bound flow scenarios are similar), is shown on Figure 2-6. Estimates of individual and system pumping rates are provided in Table 2-2, and estimated well drawdown and available head are provided in Table 2-3. Although model-predicted flow rates vary between relatively narrow bounds (250-300 gpm), the remedial action components (wells, pipelines, treatment facility) will be designed to accommodate South Interception System flow between 200 and 400 gpm. The upper bound value of 400 gpm includes additional capacity for potential system expansion and represents the maximum design flow for the South Interception System. A flow rate of 400 gpm may be beyond the capacity of the presently proposed (five well) South Interception System, and would probably only be required if additional wells are added to the system.

Because of their interaction, contaminant capture for the West Interception System and East Extraction System were evaluated as a single system. The West Interception System and the East Extraction System each include four extraction wells, although only three of the East Extraction wells are screened in the Lower Sand/Gravel Aquifer (existing Extraction Well CP-E2 is screened in the Basalt Aquifer).

The capture zone for the West Interception and East Extraction Systems was estimated by releasing a series of particles into the Lower Sand/Gravel Aquifer across the plume width at the east model boundary. Pumping rates required to obtain capture within the portion of the Lower Sand/ Gravel Aquifer impacted by the Constituents of Concern vary from about 430 gpm (lower bound scenario) to 750 gpm (upper bound scenario) for the West Interception and East Extraction Systems. The capture zone for the West Interception and East Extraction Systems, based on the upper bound flow scenario (the capture zones for the upper and lower bound flow scenarios are similar) is shown on Figure 2-7. Estimates of individual well and system pumping rates are provided in Table 2-2, and estimates of well drawdown and available head are presented in Table 2-3.

Model-predicted flow rates vary between 430 and 740 gpm for the West Interception and East Extraction Systems. However, remedial action components (wells, pipelines, treatment facilities) will be designed to accommodate combined West Interception and East Extraction System flows between 400 and 1,200 gpm. The upper bound value of 1,200 gpm includes additional capacity for potential expansion, and represents the maximum design flow for the combined flow of the West Interception and East Extraction Systems. A flow rate of 1,200 gpm is within the capacity of the proposed West Interception and East Extraction Systems, and would not necessarily require system expansion to achieve.

As noted in Section 2.1, the SOW basis for design does not require the demonstration of complete capture (concentrations of 15 to 50 percent of the Performance Standards can escape capture). However, the capture analysis performed for Phase II design (as described herein) does not predict plume breakthrough at the design pumping rates and, thus, is more conservative than the design required by the Project Consent Decree.

2.2.4 Regional Drawdown

Operation of the Phase II Interception and Extraction Systems will result in aquifer drawdown over a large (regional) area. This regional drawdown has the potential to impact available drawdown for private wells in the vicinity of the remedial action.

Drawdown for the Upper and Lower Sand/Gravel Aquifers was estimated using the MODFLOW groundwater flow models developed for interception/extraction system design. The upper bound flow scenarios were used in both cases, because they cause greater regional drawdown than the lower bound flow scenarios. Estimated regional drawdown resulting from Phase II operation for the Upper and Lower Sand/Gravel Aquifers is presented on Figures 2-8 and 2-9, respectively. Although these estimated drawdowns appear to provide a reasonable approximation of anticipated values, the accuracy of these estimates decrease with distance from the extraction wells (as the model boundaries are approached). It is anticipated that observed drawdowns may exceed the predicted values, particularly near the model boundaries.

2.3 ESTIMATED CONSTITUENT CONCENTRATIONS

Estimated constituent concentrations for extracted groundwater are required for Phase II treatment system design. Preliminary Phase II treatment system design is presented in the Preliminary Treatment and Discharge Plan (Landau Associates 1992). However, constituent concentration estimates are based on the groundwater flow models used for interception/extraction system design and, as such, the basis for developing these constituent estimates is presented in this Plan.

The constituent concentration of primary concern for treatment system design is the Constituent of Concern that controls design of the stripping tower. MC was identified as the Constituent of Concern controlling stripping tower design in the Phase I Engineering Report (Landau Associates 1991). Interception/Extraction System TCA concentrations were also estimated because of the widespread distribution of TCA in the groundwater flow system.

The Upper and Lower Sand/Gravel Aquifer groundwater flow models used for design of the South and West Interception and East Extraction Systems were used, in conjunction with a solute transport package (MT3D), to estimate peak concentrations of MC and TCA.

MT3D (Papadopoulos 1991) superimposes a constituent concentration field on the groundwater flow system represented by the MODFLOW numerical groundwater flow model. MT3D allows consideration of retardation, dispersion, and various contaminant sources. For the purpose of this Project, the concentration data for MC and TCA collected during Phase I were used to establish constituent distributions for modeling purposes. Conservative assumptions were made regarding constituent distribution and migration characteristics to produce a peak concentration with a limited potential for exceedance. These assumptions include:

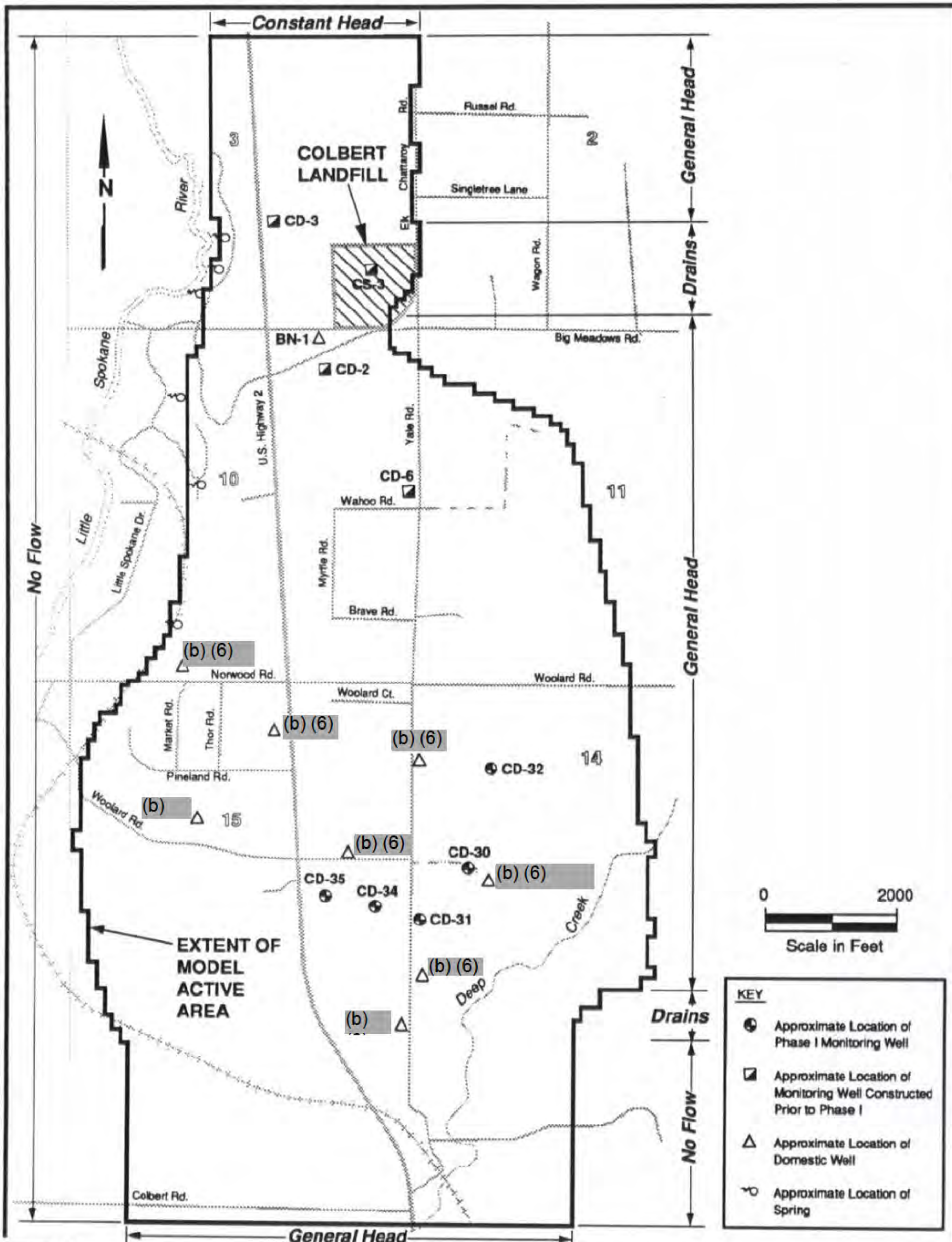
- The highest concentration observed at a given location (where multiple wells existed) represents the concentration throughout the aquifer thickness
- MC is not retarded during migration; a retardation factor of 2 is appropriate for TCA
- No constituent dispersion occurs
- There is a continuing flux of MC and TCA into the model, resulting from infiltration at the Landfill (applied to Lower Sand/Gravel Aquifer model only).

The model was run for an extended period (10-20 years) for each constituent of interest to verify that the instantaneous peak observed in model output was the maximum peak. The model-generated output included time versus concentration data for each extraction well.

Time versus concentration data for individual wells were combined on a mass flux basis into the three pipelines that will convey extracted groundwater to the Phase II treatment facility. The time versus concentration data for the three pipelines were further combined (on a mass flux basis) to develop estimated time versus concentration data for the total flux of extracted groundwater. Estimated peak concentrations of MC and TCA for individual extraction wells are provided in Table 2-4. Plots of time versus concentration for the total flux of extracted groundwater are provided on Figure 2-10 for MC and TCA. As shown on Figure 2-10, the peak estimated concentration for MC is about 500 ppb and the peak estimated concentration for TCA is 1,100 ppb.

Figure 2-10 provides a basis for estimating when peak concentration will occur. However, some of the assumptions used to produce a conservative peak concentration (no retardation for MC and no dispersion for either MC or TCA) may result in a predicted peak concentration arrival occurring earlier than the measured peak, and the rate of decrease in constituent concentration will likely be slower than the model-predicted rate. As a result, changes in concentration with time will probably at a slower rate than predicted.

Additional discussion and documentation of the solute transport modeling performed for Phase II design is provided in Appendix C.



Upper Sand/Gravel Aquifer
Model Extent and Boundary Conditions

Figure 2-1

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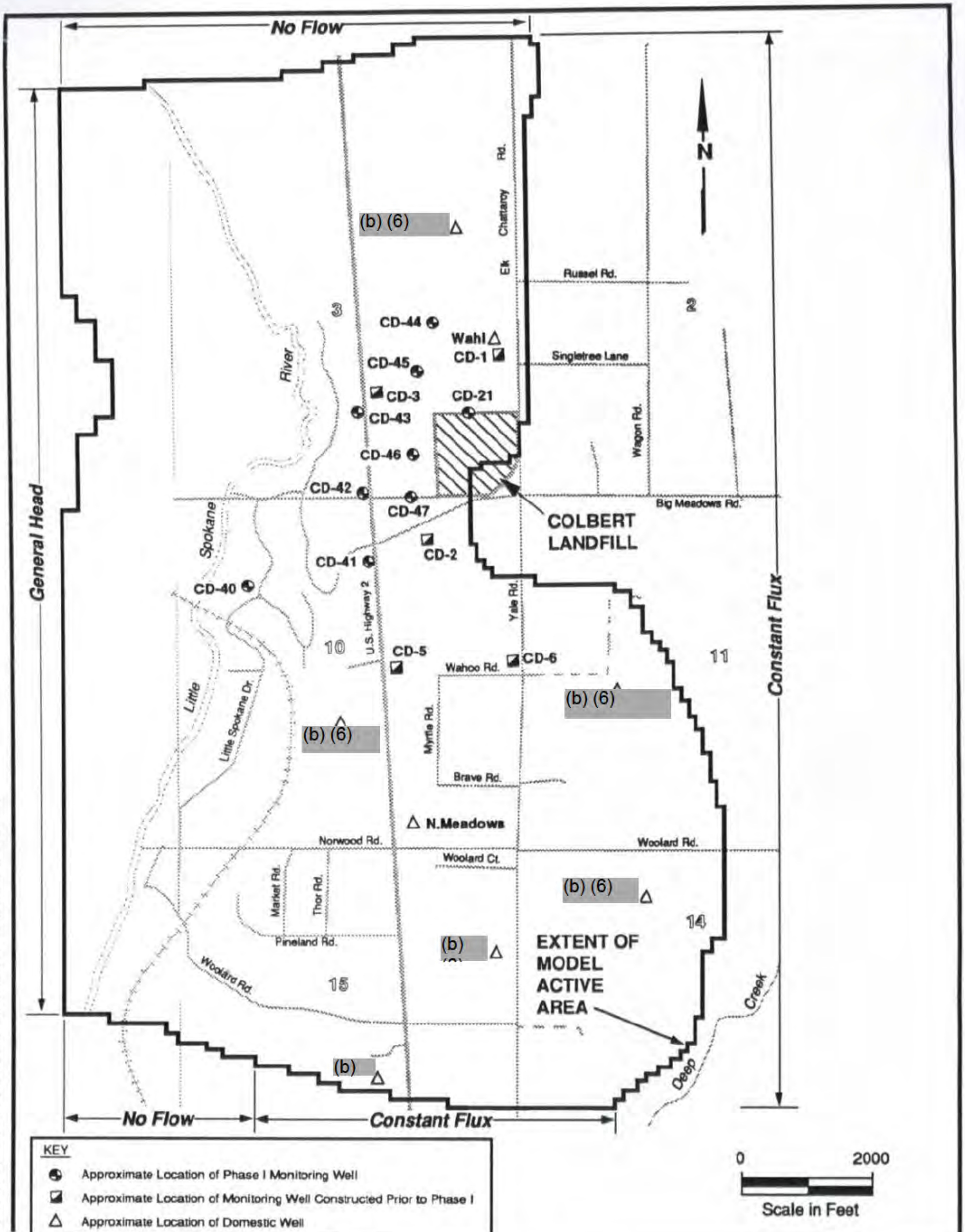
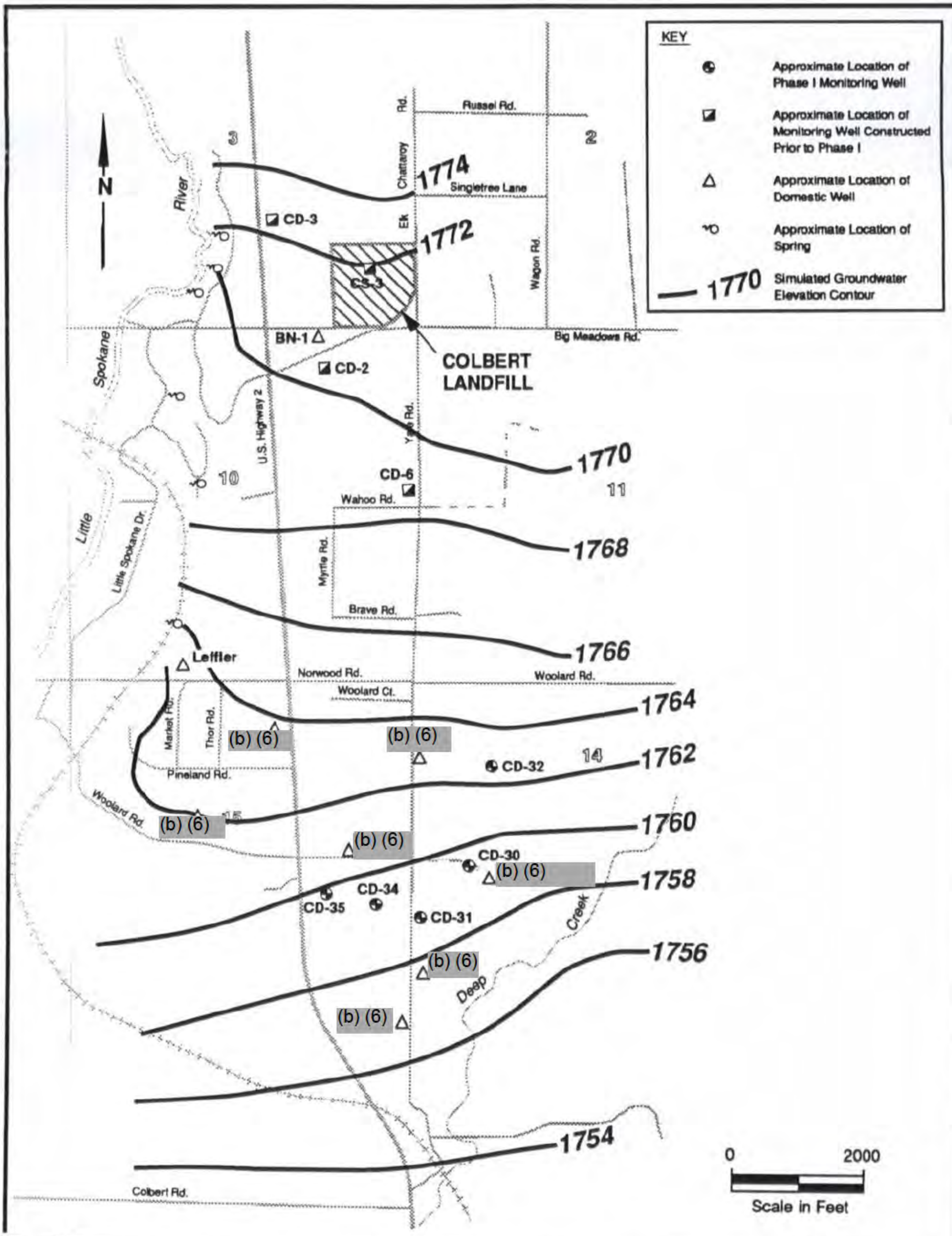
124001.72 Spokane Co./Colbert Landfill RD/RA Phase II / Final Extraction Well Plan 8/92



Lower Sand/Gravel Aquifer
Model Extent and Boundary Conditions

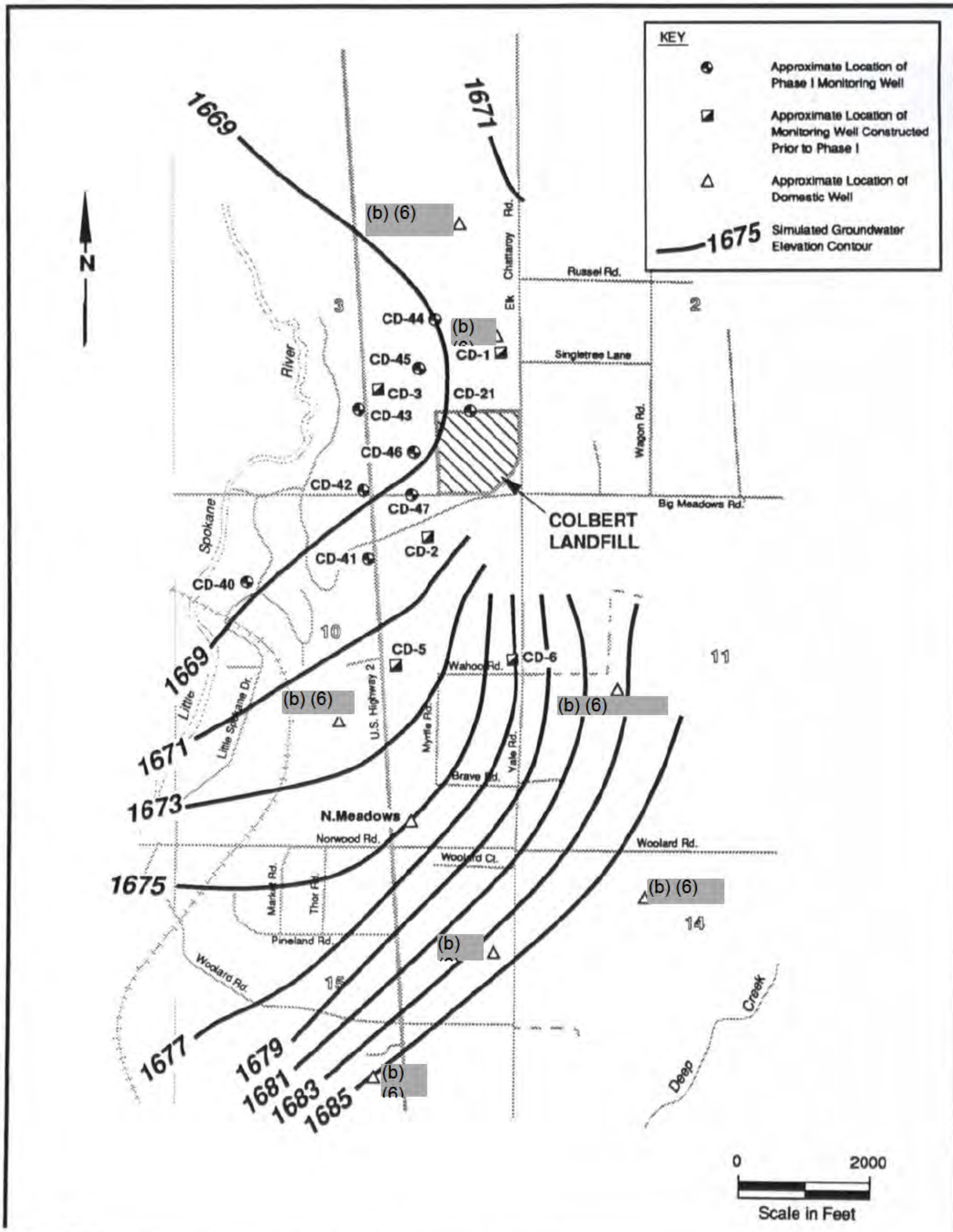
Figure 2-2



Upper Sand/Gravel Aquifer
Model Groundwater Elevation Contours (Nonpumping)

Figure 2-3

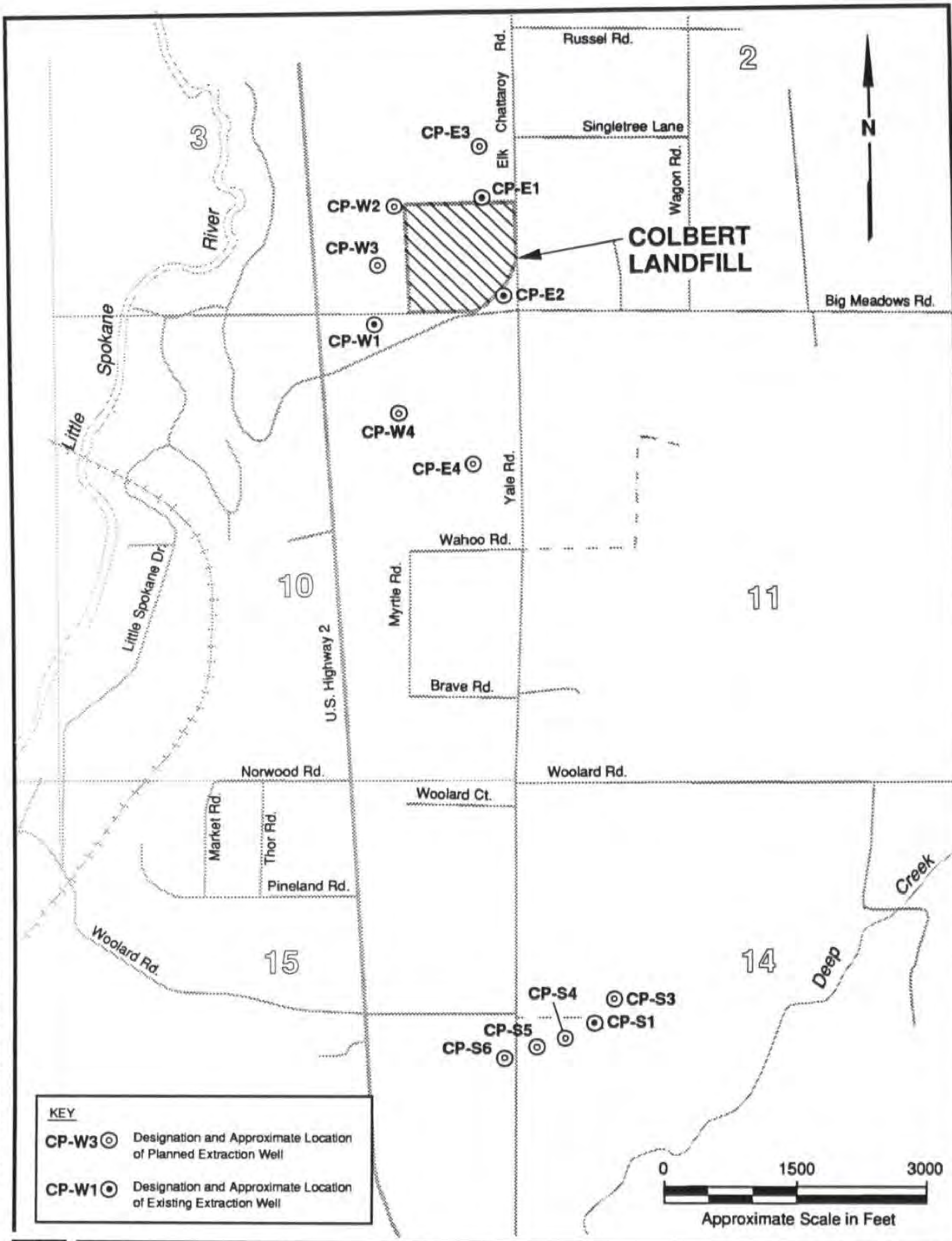
124001.72 Spokane Co./Colbert Landfill RD/RA Phase II / Final Extraction Well Plan 8/92



Lower Sand/Gravel Aquifer
Model Groundwater Elevation Contours (Nonpumping)

Figure 2-4

124001.72 Spokane Co./Colbert Landfill RD/RA Phase II / Final Extraction Well Plan 8/92



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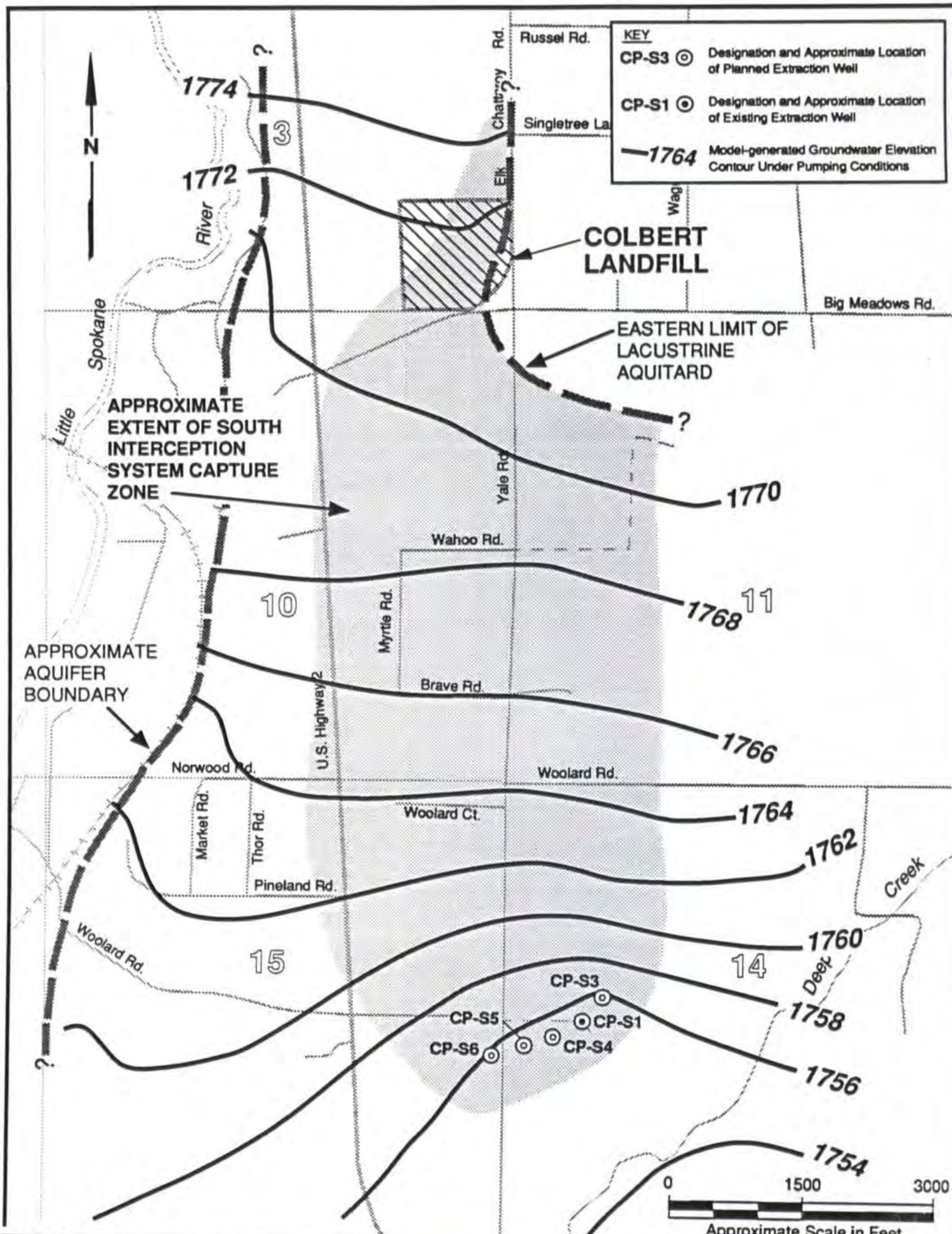
Location of Phase II Extraction Wells

Figure 2-5



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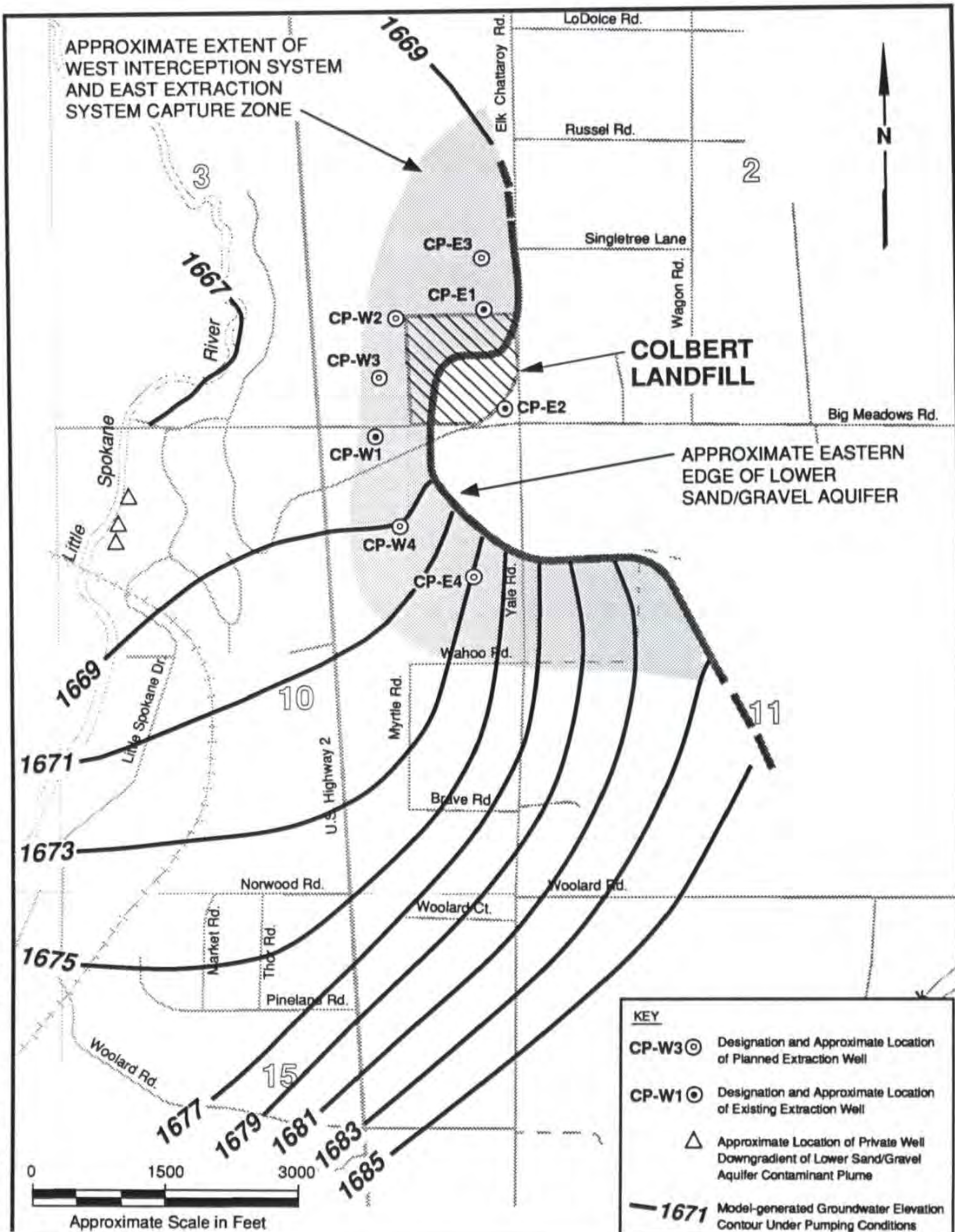
South Interception System Capture Zone

Figure 2-6



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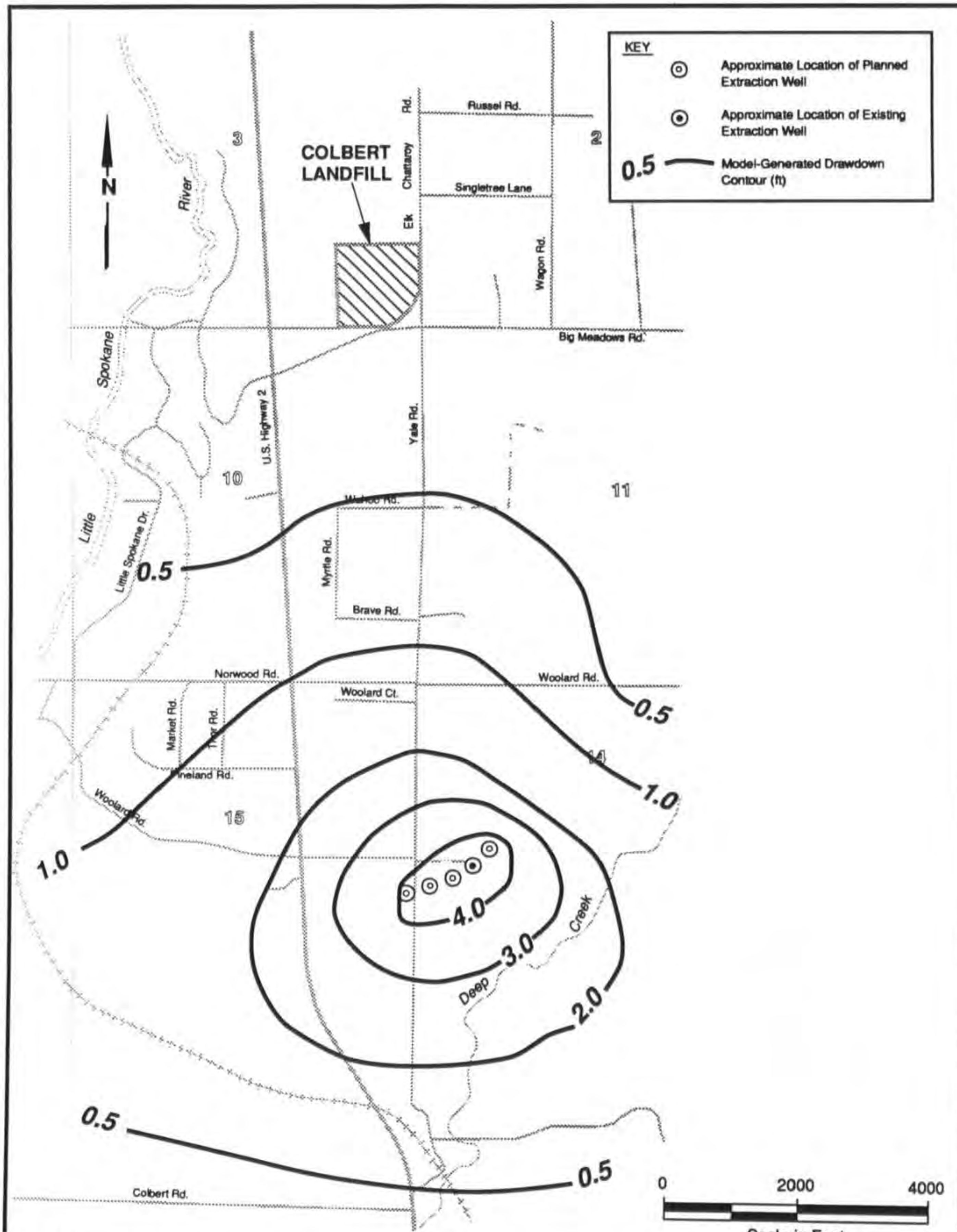
Combined West Interception and East Extraction System Capture Zone

Figure 2-7



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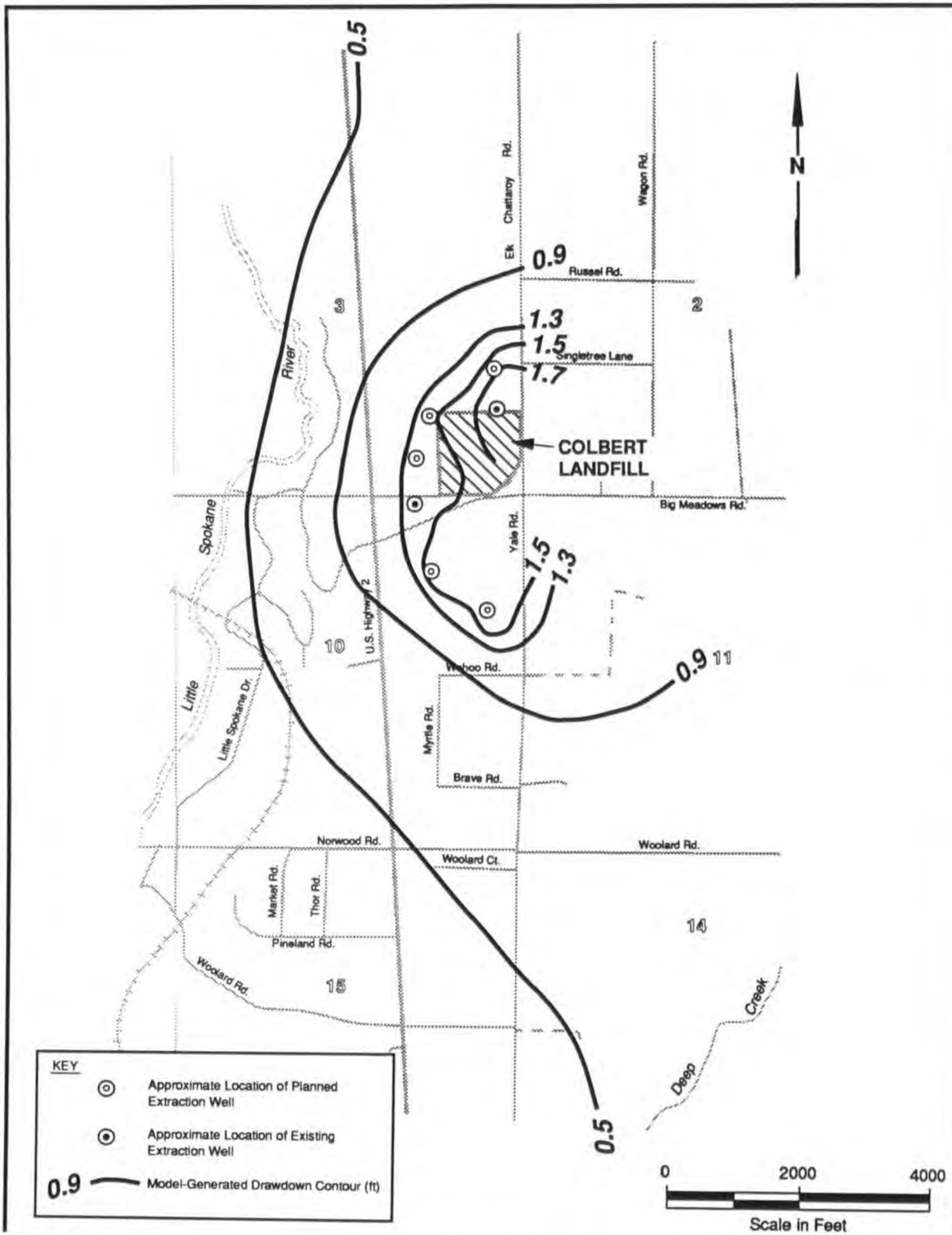
Upper Sand/Gravel Aquifer
Anticipated Regional Drawdown

Figure 2-8



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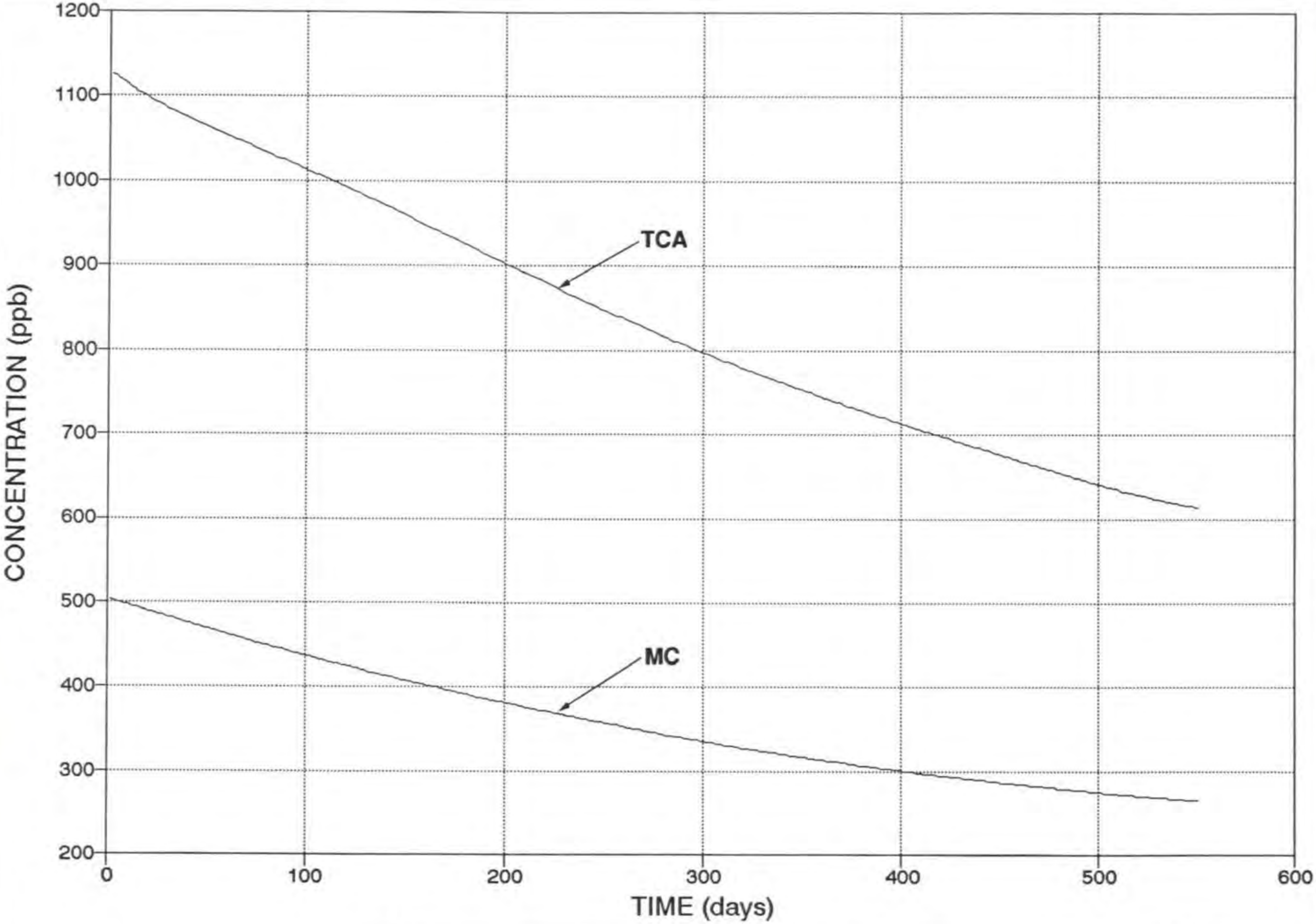
Lower Sand/Gravel Aquifer
Anticipated Regional Drawdown

Figure 2-9



Time vs. Concentration Simulation
for TCA and Methylene Chloride

Figure 2-10

TABLE 2-1

HYDRAULIC CONDUCTIVITY VALUES USED FOR
UPPER AND LOWER BOUND MODEL FLOW SCENARIOS

Aquifer Model	Hydraulic Conductivity Range for Lower Bound Flow Scenario (ft/d)	Hydraulic Conductivity Range for Upper Bound Flow Scenario (ft/d)
Upper Sand/Gravel Aquifer	410-530	500-640
Lower Sand/Gravel Aquifer	110-180	200-270

TABLE 2-2

DESIGN FLOW RATES
PHASE II INTERCEPTION AND EXTRACTION SYSTEMS[a]

Interception/ Extraction System	Extraction Well Designation	Model-Predicted		System Design	
		Lower Bound Flow Rate	Upper Bound Flow Rate	Minimum Flow Rate	Maximum Flow Rate
South	CP-S1	50	60	--	--
	CP-S3	50	50	--	--
	CP-S4	50	50	--	--
	CP-S5	50	60	--	--
	CP-S6	50	60	--	--
Subtotal		250	280	200	400
West	CP-W1	60	130	--	--
	CP-W2	70	130	--	--
	CP-W3	70	130	--	--
	CP-W4	70	130	--	--
Subtotal		270	520	250	900
East	CP-E1[b]	60	80	--	--
	CP-E2[c]	5	5	--	--
	CP-E3[b]	50	65	--	--
	CP-E4[b]	50	65	--	--
Subtotal		160	220	150	300
System Total		680	1,000	600	1,600

(a) Flow rates in gallons per minute (gpm).
(b) Flow rates predicted to assist West Interception System capture. Higher flow rates may be utilized for source control.
(c) Well not in model domain. Pumping rate based on Phase I pumping test results.

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TABLE 2-3

ESTIMATED AVAILABLE HEAD DRAWDOWN FOR PHASE II INTERCEPTION/EXTRACTION WELLS

Interception/ Extraction System	Extraction Well	Estimated Available Head[a] (ft)	Estimated Drawdown[b] (ft)
South	CP-S1[c]	13	9
	CP-S3	13	8
	CP-S4	13	8
	CP-S5	13	8
	CP-S6	13	9
West	CP-W1[c]	100	6
	CP-W2	100	5
	CP-W3	100	5
	CP-W4	100	10
East	CP-E1[c]	40	6
	CP-E2[c]	34	34
	CP-E3	20	6
	CP-E4	25	8

(a) Assumes 3 ft of available head required for pump submergence. Estimated available head based on Phase I data.

(b) Estimated well loss for South System wells assumes 60 percent well efficiency and 80 percent for West and East System wells.

(c) Existing well.

TABLE 2-4

MODEL - ESTIMATED MC AND TCA PEAK CONCENTRATIONS FOR PHASE II EXTRACTION WELLS

Well Designation	Estimated Peak Concentration (ppb)	
	MC	TCA
South System		
CP-S1	N/A[a]	180
CP-S3	N/A	190
CP-S4	N/A	350
CP-S5	N/A	620
CP-S6	N/A	620
West System		
CP-W1	0	380
CP-W2	1,300	2,500
CP-W3	460	2,800
CP-W4	0	330
East System		
CP-E1	3,400	3,800
CP-E2[b]	--	--
CP-E3	540	1,700
CP-E4	0	310

(a) N/A = not applicable.

(b) Outside of model boundary, peak concentrations not estimated.

3.0 EXTRACTION WELLS DESIGN

Extraction well design includes the design and specification of well materials and dimensions. The principal objectives of well design are:

- Highest yield with minimum drawdown
- Low sediment water
- A long operational life
- Cost-effective balance of capital, and operation and maintenance costs.

Standard well design includes selecting the casing diameter and material; selecting the length, diameter, slot size, and material for the screen; and choosing the completion method (Driscoll 1986). Well design (and construction) must also be in conformance with State of Washington well construction regulations (WAC 173-160).

3.1 WELL CASING

Well casing design includes selection of the casing material and the casing diameter. All extraction wells will be constructed using steel well casing, in conformance with WAC 173-160-225 minimum specifications for steel casing and pipe. Specifications for individual wells will depend on proposed casing diameter.

Casing diameter is selected based on anticipated well yield and/or design flow. The casing must be large enough to accommodate the pump required for the design flow, with adequate clearance, and to keep the uphole velocity to 5 ft/sec or less (Driscoll 1986). Well casings for extraction wells are designed for optimum performance at the model-predicted upper bound discharge rate, but with the capacity for significantly higher yields. Table 3-1 shows optimum and maximum yields for nominal 6-inch and 8-inch diameter wells. Table 3-2 shows the nominal casing design diameters for Phase II extraction wells.

3.2 WELL DEPTH

Well depth selection requires consideration of a number of factors. In general, the deeper the well in a given aquifer the greater the available head and, thus, the greater the potential well yield. However, aquifer hydrogeologic properties must also be considered, and the upper and lower portions of most aquifers are less uniform than the central portion. When designing an extraction system to address a contaminant plume, the vertical distribution of contaminants must also be considered.

Because of the limited saturated thickness of the Upper Sand/Gravel Aquifer (less than 20 ft), South Interception System extraction wells will be screened in the lower half of the aquifer. The limited saturated thickness also eliminates vertical contaminant distribution as a significant design consideration for the South Interception System.

Hydrogeologic data collected during Phase I indicate that, in general, the central portion of the Lower Sand/Gravel Aquifer is more uniform and coarser than the upper and lower extremes of the aquifer [see geologic logs in Appendix B of the Phase I Engineering Report (Landau Associates 1991)]. Also, analytical data indicate, for locations where the Lower Sand/Gravel Aquifer is greater than about 100 ft thick, the Constituents of Concern are primarily distributed in the upper and central portions of the aquifer [see analytical data for Monitoring Well Locations CD-21, CD-41, and CD-42 in Table F-1, Appendix F, Phase I Engineering Report (Landau Associates 1991)]. As a result, the central portion of the Lower Sand/Gravel Aquifer will be targeted for screening of Phase II East Extraction and West Interception System wells, except that East Extraction System wells located near the eastern edge of the aquifer (CP-E3 and CP-E4) may be screened near the bottom of the aquifer to achieve adequate available head.

Approximate well depths for Phase II extraction wells are provided in Table 3-2. Actual well depths require site-specific hydrogeologic and water quality data. As a result, final well depth will be selected during Phase II construction, based on aquifer material properties, and the vertical variation of specific conductance (if applicable); Phase I data indicate a general correlation between elevated specific conductance and the presence of TCA [see Section 4.3.4 of the Phase I Engineering Report (Landau Associates 1991)].

3.3 WELL SCREEN

Well screen design requires consideration of a number of factors, including:

- Well screen materials
- Screen filter pack
- Screen slot size
- Screen length.
- Groundwater entrance velocity.

Well screens for all Phase II extraction wells will be constructed of 304 stainless-steel, continuous slot, wire-wrapped screen. Telescope size and pipe size screens will be used for natural and artificial filter pack wells, respectively.

The well screen slot openings for the same formations can vary, depending on whether the well filter pack is naturally developed or an artificial filter pack is installed. Coarse-grained, well-graded formations can be developed using a natural filter pack. However, fine-grained, uniform formations typically require an artificial filter pack. Based on hydrogeologic data collected during Phase I, and experience gained during construction and operation of the Phase I pilot extraction wells (CP-W1, CP-S1, and CP-E1), West Interception and East Extraction System extraction wells will be designed with a natural filter pack and South System extraction wells will be designed with an artificial filter pack.

The screen slot-size opening is selected in the same manner for both natural and artificial filter pack wells. A slot-size opening is selected that will retain a certain percentage of the formation (or filter pack) material. Generally, a slot-size opening that will retain 30 to 40 percent of the aquifer material is selected for naturally filter-packed wells. A slot-size opening that will retain 90 percent or more of filter-pack material is typically selected for artificially filter-packed wells. The filter pack material is selected such that the effective grain size of the filter pack (typically the 30 percent passing size) is a multiple of 4 to 10 larger than the effective grain size of the formation material.

The screen slot-size opening and filter pack gradation (where applicable) will be selected on a well-by-well basis during Phase II construction, using grain-size analyses of soil samples collected within the proposed screen zone for each well. Anticipated slot-size openings and artificial filter pack gradation, based on data from pilot extraction wells constructed during Phase I, are provided in Table 3-2.

Screen length is controlled by aquifer thickness, design entrance velocities, and (in the case of plume interception) the zone within which groundwater interception is desired. Groundwater entrance velocities should be maintained below 0.1 ft/sec to minimize friction losses, and the rates of incrustation and/or corrosion (Driscoll 1986). For extraction wells intended to pump continuously for a number of years, even lower entrance velocities are appropriate (when practicable). The entrance velocity is calculated by dividing the design discharge rate by the open area of the screen section. Anticipated screen length (as screen interval), screen open area, and entrance velocities (based on upper bound design flows) for Phase II extraction wells are provided in Table 3-2.

Approximate screen intervals (and, thus, screen lengths) for Phase II extraction wells were selected based on aquifer characteristics and (for the Lower Sand/Gravel Aquifer) vertical contaminant distribution. South System extraction wells will be screened over the lower 5 to 10 ft of the Upper Sand/Gravel Aquifer. West System extraction wells will be screened over a 20 to 40 ft zone within about the central 50 percent of the Lower Sand/Gravel Aquifer. East System extraction wells will be screened for about 10 to 20 ft in the middle to lower portions of the Lower Sand/Gravel Aquifer, except for existing Extraction Well CP-E2 (which is completed open-hole in the Basalt Aquifer). East System extraction wells (CP-E3 and CP-E4) are planned for completion in the lower portions of the Lower Sand/Gravel Aquifer because limited available drawdown is anticipated at those locations.

3.4 COMPLETION METHOD

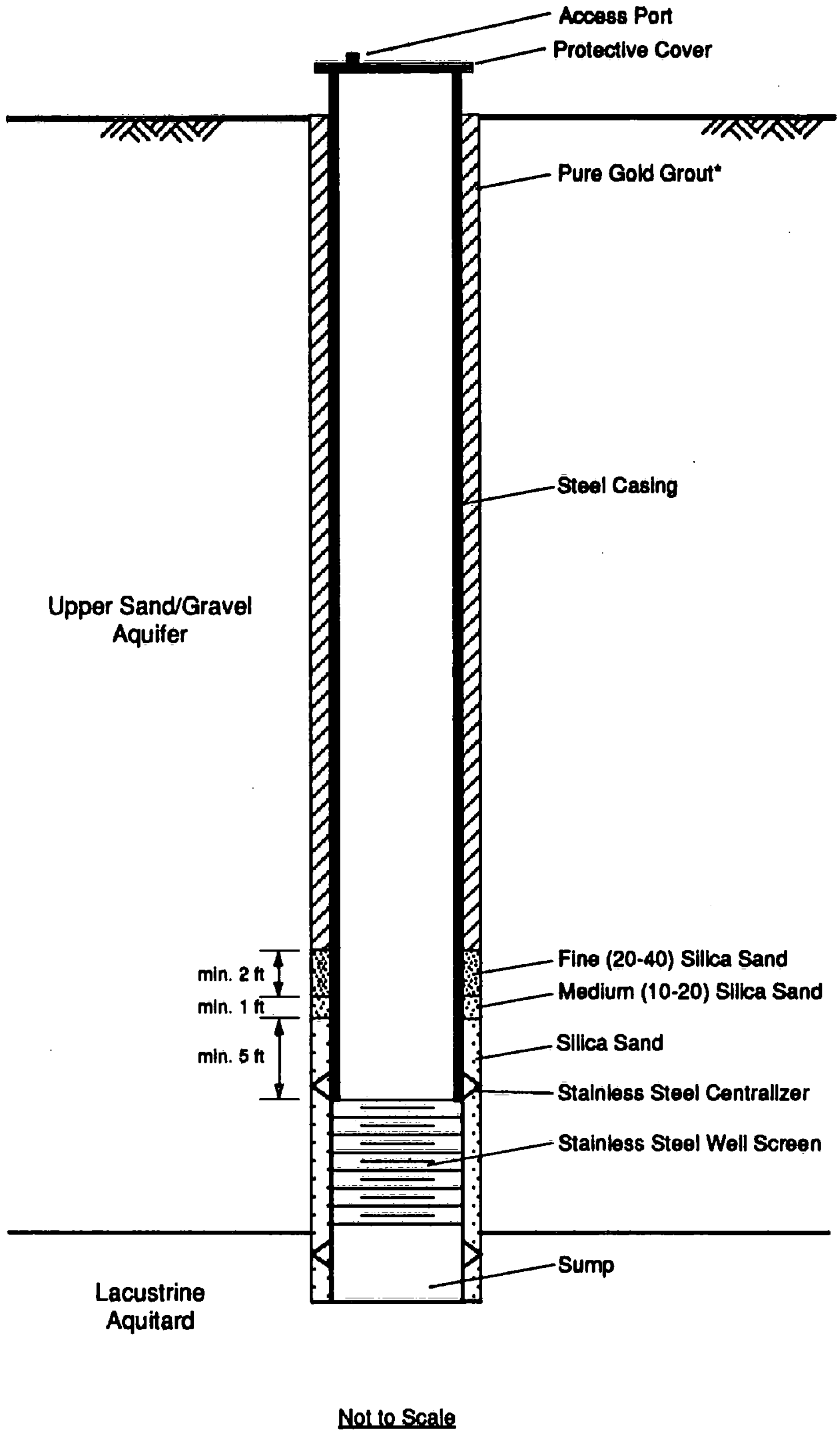
There are two primary completion methods used for water supply well construction. The pull-back method uses a telescoping screen and neoprene packer that fits inside the steel well casing driven during boring advancement. When the target depth is reached, the screen is lowered to the bottom of the boring and the steel casing is withdrawn a sufficient distance to expose the screen section. At least 5 ft of overlap between the top of the screen and bottom of the casing is typically provided. The pull-back method is commonly used for wells that do not require a filter pack, and will be used for West and East System extraction wells.

For artificially filter-packed wells, a different completion method is often used. The boring is advanced using a temporary steel casing large enough to allow the insertion of the well screen and steel casing, with enough space for placement of the filter pack around the screen section. A 3-inch thick filter pack is typically recommended. Therefore, a 12-inch diameter steel casing is required for a 6-inch diameter well completion. This completion method will be used for South Interception System extraction wells.

Washington State well construction standards require that water supply wells be completed with a minimum 18-ft grout seal, and wells that penetrate more than one aquifer must have a grout seal that extends at least 5 ft into the intervening aquitard. The grout seal must be at least 2 inches thick. For South System extraction wells, the grout seal will extend from the top of a layer of fine sand overlying the filter pack (to prevent grout intrusion) to the ground surface. West Interception and East Extraction System wells will be grouted from about 5 ft below the top of the Lacustrine Aquitard to the ground surface.

Following well completion, a temporary steel locking cover or welded plate will be placed on the well head to restrict access. The temporary steel casing will be removed when the pumping, instrumentation, and controls are constructed during subsequent Phase II construction (see Section 5.0).

Figure 3-1 provides a typical well design for a South Interception System well. Figure 3-2 provides a typical well design for a West Interception or East Extraction System well.



* Pure Gold is an American Colloid brand name.

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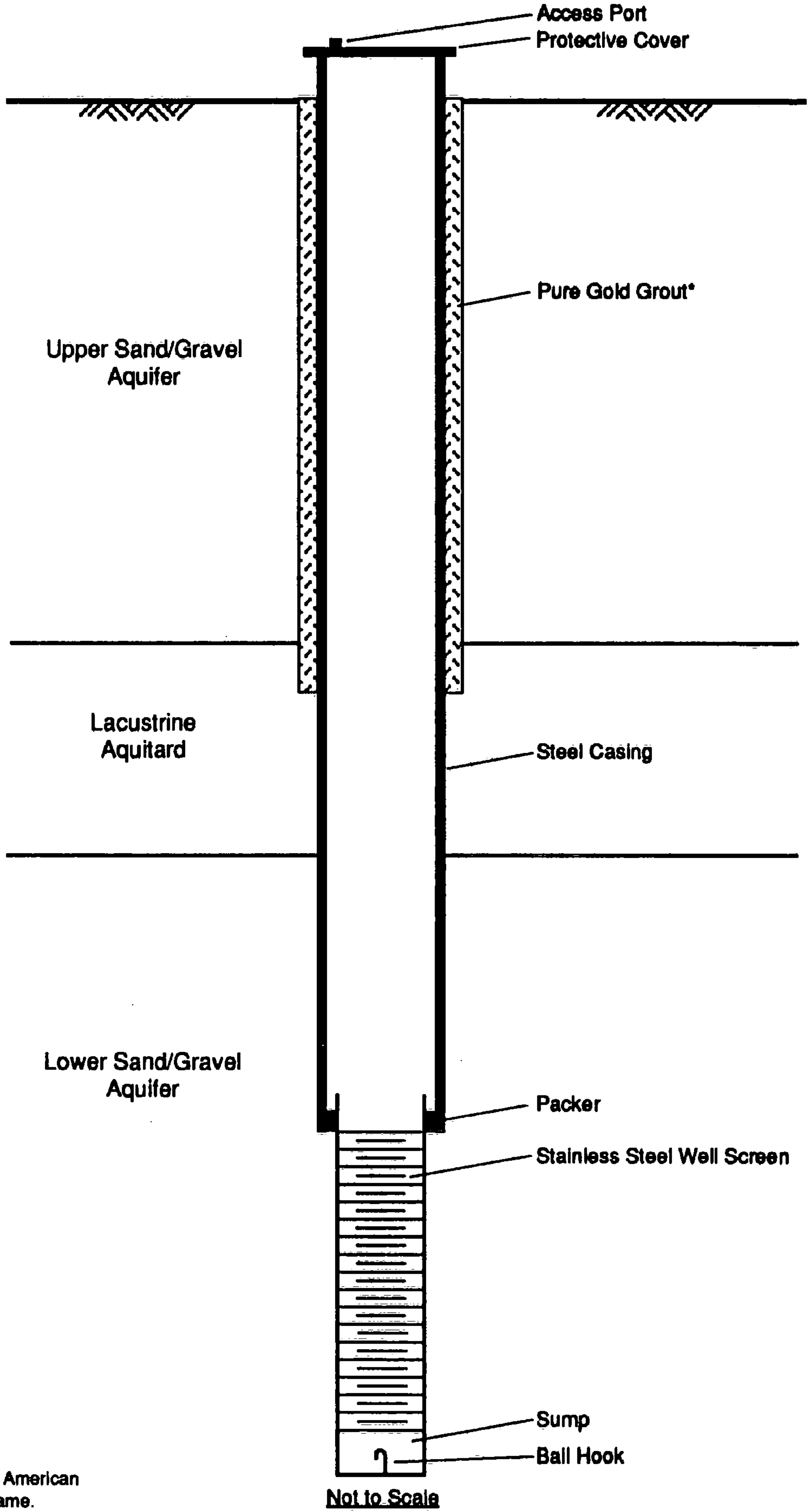
Typical Extraction Well Design
South System

Figure 3-1



* Pure Gold is an American Colloid brand name.

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Typical Extraction Well Design
West or East System

Figure 3-2

TABLE 3-1

OPTIMUM AND MAXIMUM WELL YIELDS
6-INCH AND 8-INCH WELL CASING[a]

Nominal Well Diameter	Optimum Well Yield (gpm)[b]	Maximum Well Yield (gpm)[b]
6-inch	<100	175
8-inch	75-175	350

(a) After Driscoll (1986).

(b) Yield based on casing limitations. Does not consider aquifer capacity.

TABLE 3-2

PHASE II EXTRACTION WELL PRELIMINARY DESIGN INFORMATION

Interception/ Extraction System	Extraction Well Designation	Upper Bound Design Flow (gpm)	Casing Design Diameter (inches)	Approximate Well Depth (ft BGS)	Anticipated Screen Slot Size Opening (thousandths of an inch)	Anticipated Filter Pack Gradation (US Standard Sieve No.)	Approximate Screen Interval (ft BGS)	Anticipated Open Area[(a)] (ft^2)	Anticipated Entrance Velocity[(b)] (ft/sec)
West	CP-W1[(c)]	130	8	305	40	N/A	280-300	12	0.024
	CP-W2	130	8	310	40	N/A	270-310	24	0.012
	CP-W3	130	8	310	40	N/A	270-310	24	0.012
	CP-W4	130	8	310	40	N/A	270-310	24	0.012
South	CP-S1[(c)]	60	6	110	60	6-9	100-105	3.5	0.038
	CP-S3	50	6	110	60	6-9	100-105	3.5	0.032
	CP-S4	50	6	110	60	6-9	100-105	3.5	0.032
	CP-S5	60	6	110	60	6-9	100-105	3.5	0.038
	CP-S6	60	6	110	60	6-9	100-105	3.5	0.038
East	CP-E1[(c)]	80	8	260	40	N/A	235-258	14	0.013
	CP-E2[(c)]	5	6	194	N/A	N/A	181-194[(d)]	N/A	N/A
	CP-E3	65	8[(e)]	220	40	N/A	210-220	6.0	0.025
	CP-E4	65	8[(e)]	200	40	N/A	190-200	6.0	0.025

(a) Screen length from screen interval multiplied by open area per linear ft for anticipated slot size opening. Based on Johnson Case-Type wire-wound screen.

(b) Upper bound design flow (in ft^3/sec) divided by anticipated open area.

(c) Well constructed during Phase I.

(d) No well screen, open hole interval.

(e) Casing design diameter increased beyond optimum for upper bound design flow because discharge rate for source control may significantly exceed the upper bound design flow for contaminant capture.

07/31/92 COLBERT\PHASE-II\EXT-TAB3-2

4.0 WELL CONSTRUCTION

The South, West, and East Interception/Extraction Systems will include existing wells (constructed during Phase I) and new wells (to be constructed during Phase II). This section presents the construction practices that will be used for extraction wells constructed during Phase II. A list of extraction wells to be constructed during Phase II is presented in Table 4-1. State of Washington administrative requirements for well construction (i.e., start cards and well log submitted) will be coordinated through the Eastern Regional Office of Ecology.

4.1 DRILLING PROCEDURES

Both air rotary and cable tool drilling techniques were utilized during Phase I well construction. Observations made during Phase I indicate that cable tool drilling provides higher quality hydrogeologic data than does air rotary, and is also cost effective. As a result, cable tool drilling is the anticipated drilling method for extraction wells constructed during Phase II. However, cable tool drilling is slow, and air rotary drilling may be used for West System extraction wells screened within relatively homogeneous portions of the Lower Sand/Gravel Aquifer or in close proximity to existing Phase I monitoring wells.

Soil samples will be collected during drilling activities for geologic logging and well screen design purposes. All soil samples will be logged using the soil classification system shown on Figure 4-1. Grab samples of soil cuttings will be collected at about 5- to 10-ft depth intervals for about the first 60 ft of boring advancement. Driven samples will be collected at about 5-ft intervals from about 60 ft below ground surface to the bottom of the boring.

A lithologic log of the soil and rock encountered in each boring will be maintained using a form similar to that shown on Form 4-1. Additional information, such as the presence of water-bearing zones, the depth and type of soil samples collected, and any unusual or notable conditions encountered during drilling, will also be recorded on this form.

Drilling and sampling will extend into the Lacustrine Aquitard underlying the Upper Sand/Gravel Aquifer for South System extraction wells. The borings for West and East System extraction wells will be extended to the well target depth, and may be extended to the base of the Lower Sand/Gravel Aquifer (at the discretion of Spokane County). If necessary, the casing shoe will be cut and casing separation will be verified prior to commencing extraction well installation.

The temporary casing advanced during drilling of West and East System extraction wells will be extended into the Lacustrine Aquitard to create a seal and prevent potential downward migration of contamination from the Upper Sand/Gravel Aquifer. Each West and East extraction well boring will be initiated with a 12-inch diameter temporary steel casing to allow installation of a 2-inch grout seal around the permanent 8-inch diameter permanent steel casing.

4.2 EXTRACTION WELL INSTALLATION

Extraction well installation will be accomplished in general accordance with the Washington State Minimum Standards for Construction and Maintenance of Wells (WAC 173-160). It is anticipated that cable tool equipment will be used for extraction well installation. All permanent well casing and centralizers (for filter packed wells), and equipment used downhole (such as tremie pipe) will be cleaned using a hot water pressure wash prior to installation, as described in Section 4.5.

Filter pack material (for South Interception System extraction wells) will be installed in the annulus between the temporary steel casing and the permanent well screen casing. The sand will be poured slowly from the surface. Filter pack material will be maintained approximately 3 ft above the bottom (inside) of the temporary casing to maintain formation stability. During installation of filter pack material, frequent measurements will be made to determine the depth to the top of the filter pack material, height of the filter pack above the bottom of the steel casing, and remaining distance to the planned position of the grout seal. The filter pack will be extended from at least 0.5 ft below the base of the well screen to water table surface.

A graded filter, consisting of at least 1 ft of medium sand (10-20 silica sand) followed by at least 2 ft of fine sand (20-40 silica sand), will be placed above the filter pack in South System extraction wells to minimize the possibility of grout intrusion into the filter pack. A sample of water will be obtained from the well, following placement of the initial batch of grout, to verify that grout has not intruded into the filter pack and entered the monitoring well. Similar procedures were followed during construction of Phase I wells, and filter pack grout intrusion was not observed in any of the Phase I wells.

High solids bentonite grout (Pure Gold grout) will be used to create the annular seal for all extraction wells constructed during Phase II. Pure Gold Grout achieves 30 to 35 percent solids, which is at least 50 percent greater than the 20 percent (or lower) solids achieved by standard bentonite grout. Pure Gold Grout will be placed at a unit weight of at least 10 pounds per gallon, and the grout weight will be measured periodically during placement using a mud balance.

Pure Gold grout was used as the annular sealant for most wells constructed during Phase I, and performed very well. However, excessive grout loss (approaching 100 percent) occurred in some high permeability portions of the unsaturated zone and bentonite chips were used to create a seal in these high permeability zones. Bentonite chips will be used during construction of Phase II extraction wells if similar conditions are encountered.

The annular sealant will be installed using a tremie pipe lowered to the base of the grout seal section so that water and sediment within the well casing are displaced upward when grout is pumped into the annulus. The end of the tremie line will include a fitting to divert grout flow laterally, reducing the potential for grout intrusion into the fine sand layer or underlying filter pack (for South System extraction wells). The annular sealant will be placed to the ground surface.

Well construction as-built information will be recorded on a form similar to that shown on Form 4-2. Relevant information, including drilling method, amounts and installation depths of well construction materials, and grout weights will be recorded to document final (100 percent) design of the well.

An elevation survey will be conducted following monitoring well installation to establish elevations (National Geodetic Vertical Datum) for the top of the steel casing and the ground surface. The steel casing and monument cover will be surveyed to the nearest 0.01 ft, and the ground surface will be surveyed to the nearest 0.1 ft.

4.3 WELL DEVELOPMENT

Extraction wells are developed to remove suspended formation materials introduced into the borehole and filter pack during drilling and well installation activities (for filter packed wells), and to develop a natural filter pack adjacent to the well screen (for non-filter packed wells). Proper well development results in greater well yield and lower water turbidity.

The effectiveness of different development methods vary depending on the type of aquifer materials, depth to water, height of the water column, and other factors. Air lift techniques, mechanical surging, bailing, pumping, and a combination of these methods were utilized for development of Phase I extraction wells, and were effective. These well development methods will also be used for extraction wells constructed during Phase II.

Air lift can be used for both surging and pumping wells, and is most effective for coarse aquifers, such as the Upper and Lower Sand/Gravel Aquifers. However, air lift efficiency decreases as the pumping submergence decreases (pumping submergence is the length of air line below the pumping water level divided by the total length of air line in the casing, and is expressed as a percentage). A pumping submergence of about 20 to 30 percent is typically needed for effective air lift development. It is improbable that South System extraction wells will have adequate submergence for air lift development.

For wells where air lift is not effective, development will be accomplished by a combination of surging and bailing, with final development performed by pumping with the groundwater extraction pump. Surging will be accomplished mechanically, using a surge block.

Well development will be considered complete when the discharge water appears to be low in turbidity.

4.4 DISPOSAL PROCEDURES FOR SOIL CUTTINGS AND EXCESS GROUNDWATER

Disposal procedures for soil and excess groundwater generated during extraction well drilling, development, and sampling activities are described in the Project Health and Safety Plan (Landau Associates 1992b), and are summarized in this section. Soil and groundwater will be considered nonhazardous for borings and monitoring wells located outside the Landfill refuse disposal area, provided residual volatile organic compounds are not detected at levels above background in vapors emitted from these materials.

Vapors emitted from soil cuttings and excess groundwater will be screened in the field for volatile organic compounds, using a photoionization meter. If concentrations of volatile organic compounds are present above background levels in excess groundwater, air will be bubbled through the water to remove residual volatile organics prior to disposal at the work station. Soil cuttings will be disposed of in the refuse area, if concentrations of volatile organic compounds are detected above background or if desired for aesthetic reasons. Alternatively, soil and excess groundwater may be disposed of within the refuse disposal area in lieu of screening for organic vapors.

4.5 EQUIPMENT DECONTAMINATION PROCEDURES

All material and equipment that enters (or comes in close contact with) the borehole will be thoroughly cleaned prior to use for each extraction well. Drill rigs, temporary and permanent casing, drill rods and bits, and bailers will be washed with a hot water pressure wash.

Nondedicated (soil and water) sampling equipment will be cleaned using a detergent wash and distilled water rinse. Sounding devices (water level indicators and measuring tapes) will be cleaned using a distilled water rinse. The Phase II Project Health and Safety Plan (Landau Associates 1992b) should be referred to for a more detailed description of decontamination procedures.

4.6 CONSTRUCTION QUALITY ASSURANCE

Construction quality assurance is an integral component of any construction project. It provides the basis for assessing whether construction conforms to the design specifications and, if not, whether the as-built structure is adequate to achieve its design objective.

A number of construction quality assurance procedures will be implemented for construction of Phase II extraction wells. Many (but not all) of these procedures are described in preceding sections of this Plan. This section provides a summary of construction quality assurance procedures:

- Boring advancement
  - Geologic conditions encountered during boring advancement will be logged by a geologist or engineer.
  - Exploration logs will be compared to collected soil samples for accuracy and consistency by a geologist or engineer other than the geologist or engineer that initially logged the exploration. If practicable, a single individual will provide this accuracy check for all well locations to provide a consistent description of geologic materials.
  - Daily drilling and well installation progress will be recorded on a form similar to that shown on Form 4-3.
  - The boring will be sounded, periodically, throughout the day to determine boring depth.
  - The length of steel casing will be measured and recorded each time a new casing section is added to determine the depth of steel casing.
- Well installation
  - All materials will be inspected for flaws and defects prior to installation. Materials will also be inspected to verify that they conform to the material specifications.
  - The quantities and depth of installation for all materials will be measured and documented (as shown on Form 4-2).
  - The unit weight of the annular sealant will be measured periodically, using a mud balance, to verify that the specified material density is being achieved.

- The water column within the screened zone will be checked during grout placement to verify grout has not intruded into the well casing.

- Well development

  - Monitoring well development practices will be documented on a form similar to that shown on Form 4-2.

  - A groundwater sample collected from the well subsequent to development will be analyzed for turbidity to assess the effectiveness of development.

Soil Classification System

MAJOR DIVISIONS			GRAPHIC SYMBOL	USCS LETTER SYMBOL[1]	TYPICAL DESCRIPTIONS[2][3]
COARSE-GRAINED SOIL (More than 50% of material is larger than No.200 sieve size)	GRAVEL AND GRAVELLY SOIL (More than 50% of coarse fraction retained on No.4 sieve)	CLEAN GRAVEL (Little or no fines)		GW	Well-graded gravel; gravel/sand mixture(s); little or no fines
				GP	Poorly graded gravel; gravel/sand mixture(s); little or no fines
		GRAVEL WITH FINES (Appreciable amount of fines)		GM	Silty gravel; gravel/sand/silt mixture(s)
				GC	Clayey gravel; gravel/sand/clay mixture(s)
	SAND AND SANDY SOIL (More than 50% of coarse fraction passed through No.4 sieve)	CLEAN SAND (Little or no fines)		SW	Well-graded sand; gravelly sand; little or no fines
				SP	Poorly graded sand; gravelly sand; little or no fines
		SAND WITH FINES (Appreciable amount of fines)		SM	Silty sand; sand/silt mixture(s)
				SC	Clayey sand; sand/clay mixture(s)
FINE-GRAINED SOIL (More than 50% of material is smaller than No.200 sieve size)	SILT AND CLAY (Liquid Limit less than 50)			ML	Inorganic silt and very fine sand; rock flour; silty or clayey fine sand or clayey silt with slight plasticity
				CL	Inorganic clay of low to medium plasticity; gravelly clay; sandy clay; silty clay; lean clay
				OL	Organic silt; organic, silty clay of low plasticity
	SILT AND CLAY (Liquid Limit greater than 50)			MH	Inorganic silt; micaceous or diatomaceous fine sand or silty soil
				CH	Inorganic clay of high plasticity; fat clay
				OH	Organic clay of medium to high plasticity; organic silt
HIGHLY ORGANIC SOIL				PT	Peat; humus; swamp soil with high organic content

Notes:
1. USCS letter symbols correspond to the Unified Soil Classification System. Dual letter symbols (e.g., SM-SP) for a sand or gravel indicate a soil with an estimated 5-15% fines. Multiple letter symbols (e.g., ML/CL) indicate borderline or multiple soil classifications. Only the first letter symbol's respective pattern is shown on logs.
2. Soil descriptions shown on logs are based on the general approach presented in the *Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)*, as outlined in ASTM D 2488.
3. Soil description terminology (which is based on visual estimates of the percentages of each soil type) is as follows:
   Primary Soil Type(s) - e.g., "GRAVEL," "SAND," "SILT," "CLAY," etc.
   Secondary Soil Type(s) (>15%) - e.g., "gravelly," "sandy," "clayey," etc.
   Modifier(s) (>5% and ≤15%) - e.g., "with gravel," "with sand," "with clay," etc.
   Minor Component(s) (≤5%) - e.g., either "trace gravel," "trace sand," "trace clay," etc., or no mention of minor soil type

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Soil Classification System | Figure 4-1

LANDAU ASSOCIATES, INC.
Edmonds, WA (206) 778-0907
FAX (206) 778-6409

Log of Exploration

Exploration No. ____________
Sheet ________ of ________

Client/Owner ____________ Project No. ____________

Start Date ____________ Hour ____________

Ground Surface Conditions ____________

Weather Conditions ____________

Landau Rep. ____________ Contractor/ Operator ____________

Exploration Method ____________

Hammer Weight & Stroke ____________

Location Sketch (show dimensions to mapped features)

North Arrow

Surface Elevation ____________ Datum ____________

Water Level Information			
Date			
Time			
Depth to Water			
Hole Depth			
Casing Depth			

Sample No./ Sampler Type	P.I.D. Reading	Penetration Resistance/6 in.	Length Driven	Sample Length Recovered	Sample Depth (ft.)	Graphic Recovery	Depth Scale (ft.)	USCS Symbol	Soil Description	Comments
							0			
							1			
							2			
							3			
							4			
							5			
							6			
							7			
							8			
							9			
							0			
							1			
							2			
							3			
							4			
							5			
							6			
							7			
							8			
							9			
							0			

■ Undisturbed Sample ☒ Disturbed Sample ☐ No Recovery

Sampler: SPT, 2.4-in. ID Drive (2.4 D), Thinwall (TW), Shelby Tube (S), Bulk (B), etc. (Add "C" to sampler type if a catcher is used)

Finish Date ____________ Hour ____________ Continued ☐

3/90

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Form 4-1

LANDAU ASSOCIATES, INC.
Edmonds, WA (206) 778-0907 FAX (206) 778-6409

As-built Well Completion Form

Project: ____________________
Project No.: ____________________
Well(s) No.: ____________________
Drilling Co.: ____________________
Installation Start Date: __________ Hour: ______
Installation Finish Date: __________ Hour: ______
Well Type: ☐ Single ☐ Nested ☐ Clustered

EQUIPMENT USED

- ☐ Hollow Stem Auger
- ☐ Cable Tool
- ☐ Air Rotary
- ☐ Other ____________________

MATERIALS USED

______ Sacks of ____________ Sand

______ Sacks of ____________ Concrete/Cement

______ Sacks of ____________ Grout Mix Used

______ Sacks of Powdered Bentonite

______ Pounds of Bentonite Pellets/Chips

______ Feet of ______ Inch PVC Blank Casing

______ Feet of ______ Inch PVC Slotted Screen

____

____

____

GROUT WEIGHT

Date:	Time:	Grout Wt.*
Date:	Time:	Grout Wt*
Date:	Time:	Grout Wt.*
Date:	Time:	Grout Wt.*
Date:	Time:	Grout Wt.*

* lbs./gal.

DEVELOPMENT

Method of Development:

Begin Date: Time:

Finish Date: Time:

Yield: Time From: To: Date:

Estimate of Total Water Removed During Development: Gallons

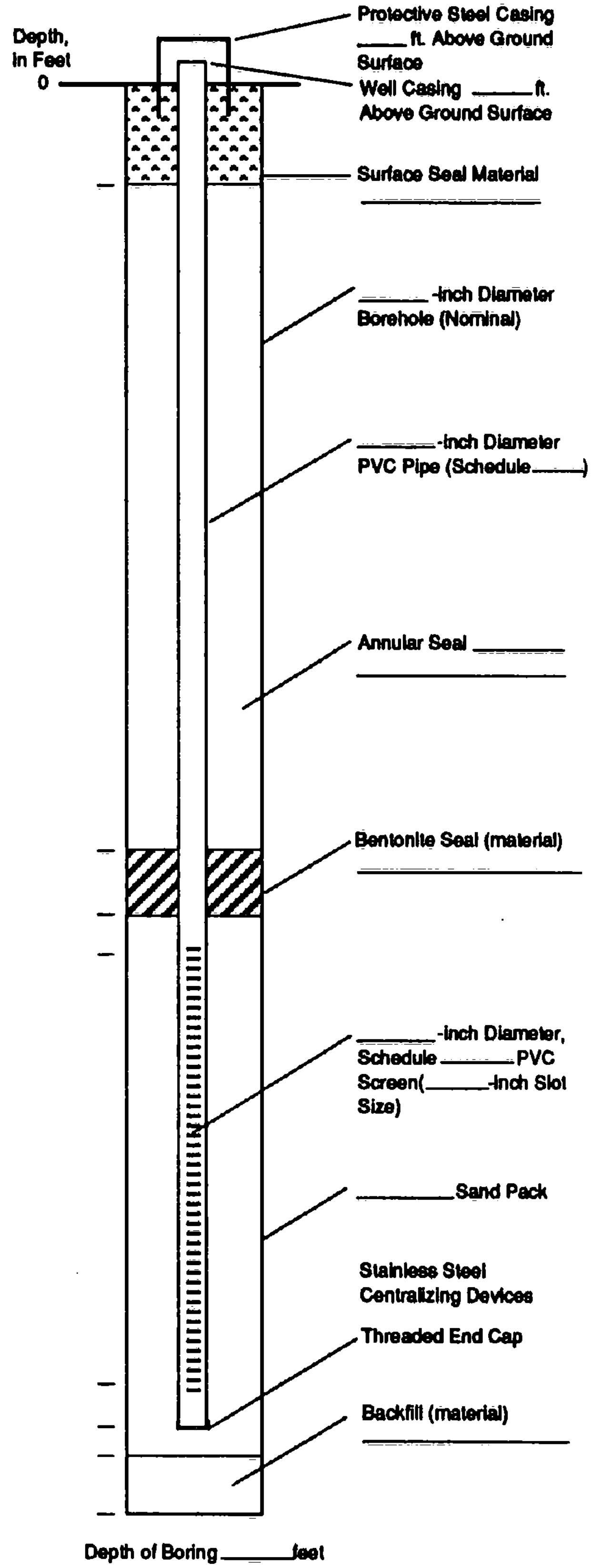
Description of Turbidity at End of Development: ☐ Clear ☐ Slightly Cloudy ☐ Mod. Turbid ☐ Very Cloudy

Odor of Water:

Water Discharged To:

Depth to Water After Development: Feet

3/91



Form 4-2

LANDAU ASSOCIATES, INC.
Edmonds, WA (206)778-0907

Project ______________________

Job No. ______________________

Drilling Co. ______________________

Well No. ______________________

Log of Well Construction Progress

			DRILLING BGS (ft.)		INSTALLATION BGS (ft.)		
Date	LAI Rep	Driller Rep	Start	Finish	Start	Finish	Comments

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2/92

Form 4-3

TABLE 4-1

EXTRACTION WELLS PLANNED FOR CONSTRUCTION DURING PHASE II

Interception/ Extraction System	Well Designation
West	CP-W2
	CP-W3
	CP-W4
South	CP-S3
	CP-S4
	CP-S5
	CP-S6
East	CP-E3
	CP-E4

5.0 PUMPING, INSTRUMENTATION, AND CONTROLS

Operation of a groundwater extraction system requires consideration of well pumping requirements, and instrumentation and controls to integrate groundwater extraction with treatment system operation. This section describes extraction well pumping requirements, and preliminary design of instrumentation and control systems.

5.1 PUMPING

Anticipated Phase II extraction well pumping rates vary from about 5 gpm to 130 gpm, with anticipated lifts of between 80 and 200 ft. These are relatively low pumping rates and moderate lifts for supply wells, and can be most economically accommodated using submersible turbine pumps. Pumps will be selected to provide cost-effective groundwater extraction (considering both capital costs, and operation and maintenance expenses). Pump design considerations include:

- Well yield
- Well diameter
- Total dynamic head
- Horsepower requirements
- Power source requirements
- Net positive suction head (NPSH)
- Capital costs, and operation and maintenance costs.

Anticipated well yield and diameter design are presented in Section 3.0. Total dynamic head consists of the pump lift head, elevation head (including lift to the top of the stripping tower), and friction head losses from the pump column, conveyance piping, and fittings. Total dynamic head estimates for Phase II extraction wells are presented in Table 5-1, and calculations are provided in Appendix D.

Horsepower requirements describe the power required to provide the required well yield at a given total dynamic head. Horsepower requirements are typically expressed in terms of brake horsepower, which accounts for power loss due to pump and motor inefficiencies.

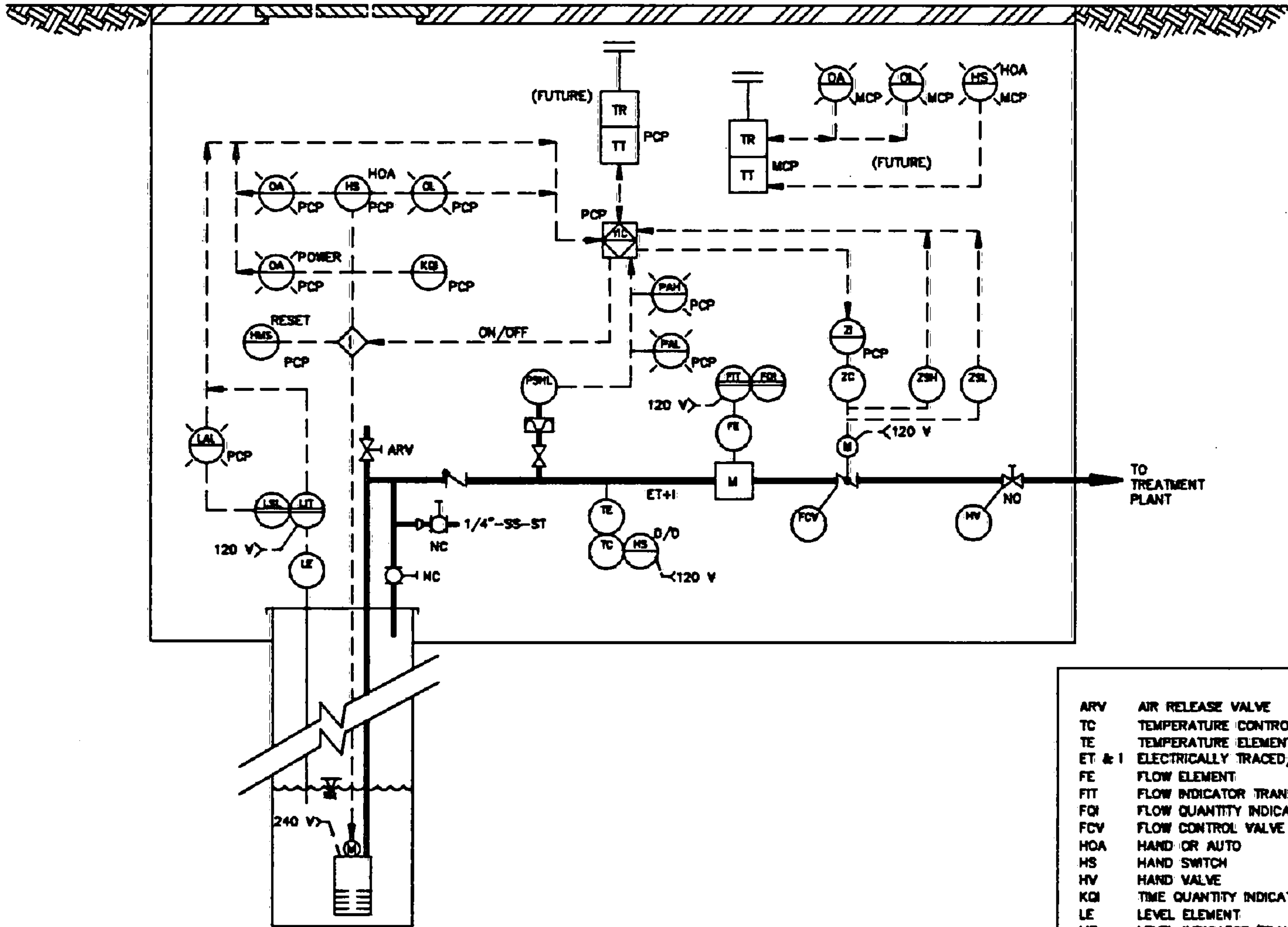
Table 5-1 provides preliminary estimates of brake horsepower; brake horsepower calculations are provided in Appendix D.

Power source requirements, NPSH, and pumping costs are dependent on characteristics of specific pumps, power grid characteristics, and other considerations that have not been evaluated as yet. These considerations will be addressed in subsequent design submittals.

5.2 INSTRUMENTATION AND CONTROLS

Instrumentation and controls are required for extraction well operation to integrate groundwater extraction with treatment system operation. Controls are required to start up and shut off extraction wells under various operating conditions, adjust extraction rates, and provide positive shutoff of flow (including backflow) for each extraction well. Instrumentation is required to monitor extraction well discharge rates, extraction well (on/off) operational settings, and, possibly, well water level (the cost effectiveness of manual versus instrumental water level monitoring is presently being evaluated).

A preliminary instrumentation and control diagram for a Phase II extraction well is provided on Figure 5-1. It is anticipated that a master control panel for operation of extraction and treatment systems will be located at the treatment facility. As such, separating design of instrumentation and control for treatment and extraction facilities is unnecessary. As a result, subsequent design for extraction well instrumentation and controls will be submitted with treatment and discharge system design submittals.



KEY

ARV	AIR RELEASE VALVE	TC	TEMPERATURE CONTROLLER
TC	TEMPERATURE CONTROLLER	TE	TEMPERATURE ELEMENT
TE	TEMPERATURE ELEMENT	TR	TELEMETRY RECEIVER
ET & I	ELECTRICALLY TRACED/INSULATED	TT	TELEMETRY TRANSMITTER
FE	FLOW ELEMENT	YIC	PROGRAMMABLE LOGIC CONTROL
FIT	FLOW INDICATOR TRANSMITTER	ZI	POSITION INDICATOR
FQI	FLOW QUANTITY INDICATE	ZC	POSITION CONTROL
FCV	FLOW CONTROL VALVE	ZSH	POSITION SWITCH HIGH
HOA	HAND OR AUTO	ZSL	POSITION SWITCH LOW
HS	HAND SWITCH		CHECK VALVE
HV	HAND VALVE		HAND OPERATED VALVE
KQI	TIME QUANTITY INDICATE		BALL VALVE
LE	LEVEL ELEMENT		INTERLOCK
LIT	LEVEL INDICATOR/TRANSMITTER		MECHANICALLY ACTIVATED VALVE
LSL	LEVEL SWITCH LOW		MAGNETIC FLOW METER
LAL	LEVEL ALARM LOW		
HMS	HAND MOMENTARY SWITCH		
MCP	MAIN CONTROL PANEL		
OA	OPERATING ALARM		
O/O	ON/OFF		
OL	OPERATING LIGHT		
PAL	PRESSURE ALARM LOW		
PAH	PRESSURE ALARM HIGH		
PCP	PUMP CONTROL PANEL		
PSHL	PRESSURE SWITCH HIGH\LOW		

Phase II
Extraction Well Instrumentation Control Diagram

Figure 5-1

TABLE 5-1

TOTAL DYNAMIC HEAD AND BRAKE HORSEPOWER ESTIMATES FOR PHASE II EXTRACTION WELLS

Interception/ Extraction System	Well Designation	Elevation Head[a] (ft)	Friction Head (ft)	Total Dynamic Head[b] (ft)	Required Pump Brake Horsepower[c] (HP)
West	CP-W1[d]	264	14	278	16
	CP-W2	266	17	283	17
	CP-W3	265	16	281	16
	CP-W4	259	14	273	16
South	CP-S1[d]	168	17	185	5
	CP-S3	168	17	185	4
	CP-S4	164	16	180	4
	CP-S5	160	18	178	5
	CP-S6	159	17	176	5
East	CP-E1[d]	264	8	272	10
	CP-E2[d]	234	3	237	0.5
	CP-E3	260	7	267	8
	CP-E4	253	11	264	8

(a) Includes lift from static water level, change in elevation, and 70-ft lift to top of stripping tower.

(b) Elevation Head + Friction Head.

(c) Assumes 70 percent pump efficiency, and 25 percent factor of safety on total dynamic head.

(d) Existing well.

07/31/92 COLBERT\PHASE-II\EXT-TAB.5-1

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APPENDICES

APPENDIX A

Section V of the Project Consent Decree Scope of Work

(Reformatted from the Original)

COLBERT LANDFILL RD/RA
CONSENT DECREE SCOPE OF WORK

SECTION V.
Phase II Design and Operation

A. Extraction, Water Treatment, and Discharge - South System

1. **Bases for Design** --

a. The goal of the south ground water interception system is to prevent the spread of contaminated ground water downgradient(1) of the interception system. Both the Government Plaintiffs and the County recognizes that the interception system, during operation, may not capture 100 percent of the plume which contains constituents of concern, but consider it reasonable to design an interception system which approaches this goal.

b. Location of the Interception System -- The ground water interception system will be located based on information developed during Phase I pilot studies. Important considerations in placement of the interception system will include: concentrations and areal distributions of contaminants in the ground water; and hydrogeologic conditions identified during Phase I, such as saturated thickness of the aquifer, hydraulic conductivity, hydraulic gradients, and aquifer boundary conditions.

c. Treatment System -- The treatment system will be designed to meet the Performance Standards at the point of discharge from the treatment system. This design will be based on the maximum anticipated contaminant mass influent rate and treatment efficiency levels demonstrated during Phase I pilot testing. Compliance with applicable air emission standards will be addressed during treatment system design in accordance with the provisions of Section V.D.

d. Cost Effectiveness -- Design of the Phase II interception/treatment/discharge system will also consider cost effectiveness. The minimum level of effort required for the south interception system is prevention of the spread of the constituents of concern at concentrations which exceed the evaluation criteria identified in Table IV-1. The treatment and discharge

(1) For the purpose of this Scope of Work, the terms upgradient and downgradient refer to the ground water gradient under non-pumping, steady state conditions, unless specifically indicated otherwise.

system must meet the evaluation criteria. The County, at its discretion, may either select proven technology or new technologies which attain these criteria more economically. The system plans will be submitted to the Government Plaintiffs for review and approval.

2. **Design Components and Bases for Decision**--

a. Monitoring -- The County may, at its discretion, decide, following completion of Phase I, to install up to three additional monitoring wells to better characterize the hydrogeology and contaminant distribution in the shallow aquifer. If so decided, the County will provide plans to the Government Plaintiffs for review, identifying the number and location of additional monitoring wells. Information from these wells would be used to confirm or refine data from Phase I prior to construction of the Phase II system.

As the plan for the Phase II ground water interception system is finalized, a ground water monitoring program will be instituted to evaluate interception system performance. The interception system monitoring wells will consist of at least three, and not to exceed eight, monitoring wells located downgradient of the ground water interception system, and two monitoring wells placed at the outer limit of the interception system. The wells at the outer limits will also serve as extraction wells, if adjustment control criteria (as described in Section V.A.2b) are exceeded in these wells during monitoring. The County will determine if the interception system monitoring wells will include wells installed as part of the Phase I program. Phase I wells not included as interception system monitoring wells will be monitored at the County's discretion. A more extensive monitoring system may be proposed by the County if they determine that additional monitoring is appropriate. Plans for additional monitoring would be provided to the Government Plaintiffs for review and approval.

Chemical analysis for the interception system monitoring wells will be accomplished for the four indicator compounds identified in Table V-1, using EPA Method 8010 (SW-846, USEPA, 1986), on the frequency described in the following paragraph. Methylene chloride and tetrachloroethylene have been excluded from Table V-1 due to the high probability of laboratory contamination for methylene chloride, and the limited distribution in the ground water of both methylene chloride and tetrachloroethylene. Although methylene chloride and tetrachloroethylene do not form the basis for interception system design and operation criteria, they will be included in chemical analysis annually for at least the first five years of system operation. If methylene chloride and/or tetrachloroethylene are detected at concentrations above the Table IV-1 evaluation criteria during Phase I or during annual sampling described in this paragraph, the compounds will be monitored at the frequency of the other compounds listed in Table V-1. After this five-year period, the need for continued analysis for methylene chloride and tetrachloroethylene will be re-evaluated.

Quarterly sampling and analysis will be conducted for each of the interception system monitoring wells, except that the performance monitoring wells will initially be sampled more frequently as subsequently described in Section V.A.2b. Quarterly sampling of each well will be continued until no exceedance of the operational control criteria (as described in Section V.A.2b) is identified for twelve consecutive quarters. In the event that, for a particular well, no exceedances occur during the twelve quarters, sampling frequency will be reduced to an annual basis for the next two years. If no exceedances have been identified during this five-year period, the County will, with Government Plaintiff's approval, determine whether continued monitoring is appropriate based on the need to assure long-term protection of purveyor wells at the site. If, in a particular monitoring well (or converted extraction well, as described below in Section V.A.2b.), no exceedances occur, but an increasing trend in concentrations is identified that is likely to result in exceedance of the operational control criteria, the County will implement a longer-term sampling and analysis program that assures the protection of human health.

In the event that a single exceedance of an applicable criteria (Table IV-1 or Table V-1) occurs, a follow-up sample will be obtained. An exceedance will be confirmed if concentrations exceeding an applicable criteria are identified in three consecutive samples collected at two-week intervals. If an exceedance is confirmed, the County will submit, for the Government Plaintiffs' review and approval, a program including additional monitoring wells or additional monitoring of existing wells to address the exceedance.

The criteria presented in this section (V.A.2a) applies only to monitoring during system operation. While the interception system is shut off and on standby status, this system operation criteria is superseded by the monitoring criteria described in Section X of this Scope of Work.

b. Interception System -- In order to meet the goals identified in Section V.A.1a, the County will accomplish the following:

- Conduct the Phase I pilot studies to obtain the needed aquifer characteristics for designing an interception system.

TABLE V-1

OPERATIONAL AND ADJUSTMENT CONTROL CRITERIA[a]

Compound	Maximum Operational Control Criteria[b] (ppb)	Maximum Adjustment Control Criteria[c]
1,1,1-Trichloroethane	60	130
1,1-Dichoroethylene	NA[d]	5
1,1-Dichloroethane	1,200	2,600
Trichloroethylene	NA[4]	4

(a) Maximum criteria are presented in this table. Criteria may be lower than these values, as described in Sections V.A.2b. and V.C.2b. of this Scope of Work.

(b) Operational control criteria as represented by 30 percent of the Table IV-1 evaluation criteria.

(c) Adjustment control criteria as represented by 65 percent of the Table IV-1 evaluation criteria.

(d) Resulting concentration is too low to be accurately quantified using standard laboratory procedures. This constituent will not be included as part of the operational control criteria.

- Complete a preliminary design engineering report detailing the most probable aquifer characteris- tics, design parameters and project costs. The system will be designed utilizing capture zone analysis to achieve overlapping cones of depression, and such that the total pumping capability of the interception well system is sufficient to intercept the plume to the extent described within this section (V.A.2b). Selection of pumping test methodologies and capture zone analysis will be subject to the review and approval of the government plaintiffs.

The extraction wells will be installed near the leading edge of the plume. Extraction wells will be installed in succession from the center to the outermost limits of the plume. The spacing of the wells will be determined by the County based on hydrogeologic and chemical data. Additional wells will be installed until the ground water at the outermost limits is below the adjustment control criteria. The outermost wells will be included as interception system monitoring wells, and will be constructed such that conversion to extraction wells is possible if exceedances of adjustment control criteria are subsequently identified. If an outboard monitoring well is converted to an extraction well, an additional monitoring well (constructed for possible conversion to an extraction well) will be installed to the outside of the converted monitoring/extraction well.

The design criteria will serve as a guide to the use of the aquifer capture analysis referred to earlier in this section. The basis for the south interception system design will be that the average concentrations of the contaminants of concern in the upper aquifer downgradient of the interception system are predicted to be no greater than 15 percent of the Table I-1 Performance Standards based on capture zone analysis.

Commencing at a mutually agreed upon time following startup of the interception system, the downgradient interception system monitoring wells will be sampled monthly (for Table V-1 constituents) for two years, or some other mutually agreed-upon length of time. The Government Plaintiffs will select at least three, and not to exceed eight, of these downgradient wells for use as performance monitoring wells. These wells will be selected to provide a representative sampling of constituent concentrations across the full width of the interception system. Based on statistical analysis of the chemical data from these performance monitoring wells, a baseline concentration[2] will be identified for each Table V-1 constituent. This baseline concentration will be equal to the average of the time-averaged concentrations in the three (or more) performance monitoring wells after the data associated with the expected gradual changes following startup are eliminated.

Operational control criteria for the south interception system will be developed for the appropriate indicator compounds (1,1,1-TCA and 1,1-DCA) from Table V-1 and will be equal to the lesser of: 1) the baseline concentration plus 15 percent of the Table IV-1 evaluation criteria or 2) 30 percent of the Table IV-1 Adjustment control criteria for the south interception system will be developed for the indicator compounds from Table V-1 and will be equal to the lesser of: 1) the baseline concentration plus 50 percent of the Table IV-1 evaluation criteria or 2) 65 percent of the Table IV-1 evaluation criteria.

If after confirmation (as defined in Section V.A.2a), the average concentration in the three designated downgradient monitoring wells exceeds the adjustment control criteria for two consecutive quarters (or some other mutually agreed-upon timeframe that will better allow reflection of system adjustments in downgradient monitoring wells) following system adjustment (as described previously for operational control criteria exceedances), the interception system will be modified. Additionally, the interception system will be modified if any individual downgradient performance monitoring well exceeds the Table IV-1 evaluation criteria for two consecutive quarters (or other time period, as described above). Modifications may include increasing pumping rates (for one or more wells), adding extraction wells to the system, or other methods of correcting interception system deficiencies. The County will submit a proposal for interception system modifications to the Government Plaintiffs for review and approval.

In addition to the operation and adjustment control criteria described above, should any downgradient performance monitoring well, following the development of baseline concen-

(2) If the resulting concentration is below the Practical Quantitation Limit (PQL) for a Table I-1 constituent, the PQL reported for EPA Method 8010 (USEPA, "Test Methods for Evaluating Solid Waste," SW-846, 3rd Ed. 1986) will be used as the baseline concentration for that constituent. evaluation criteria. If, after confirmation (as defined in Section V.A.2a) the average concentration in the three performance monitoring wells exceeds the operational control criteria, the County will re-evaluate the operation of the interception system. Should this re-evaluation indicate adjustments to the system are appropriate, the County will submit a proposal for interception system adjustment to the Government Plaintiffs for review and approval. Adjustments may include increasing pumping rates (for one or more wells), or other adjustments to the existing system considered appropriate for improving interception system efficiency.

trations, exhibit anomalous concentrations or trends in concentrations that are inconsistent with effective interception system performance (such as an increasing trend in concentration projected to lead to a long-term exceedance of the Table V-1 adjustment control criteria), the County will evaluate the operation of the interception system. This evaluation will address the potential cause(s) of the anomaly and possible system adjustments or modifications (if appropriate), and will be presented to the Government Plaintiffs in a written report for their review within 60 days of evaluation.

Prior to establishing baseline concentrations, the operational and adjustment control criteria for the interception system will be the Table IV-1 evaluation criteria. These criteria will be applied on an individual basis to each downgradient interception system monitoring well.

If it is determined by the County that an exceedance of the above criteria is the result of supply well interference with the interception system, adjustment to, or modification to, the system will include elimination of the interference. Elimination of the interference may require either partial or complete cessation of supply well use. The County will attempt to negotiate a settlement with the well owner. If an equitable agreement cannot be reached between the County and the well owner, the Government Plaintiffs may use their statutory authority to seek termination of usage for the interfering well.

Based on cost effectiveness or a determination by the County that acceleration of the cleanup is appropriate, the County may, at its discretion, propose additional upgradient extraction wells. Any such proposal will be submitted to the Government Plaintiffs for review and approval.

If ground water withdrawn by an extraction well meets the operational control criteria for two consecutive quarterly samplings, water from this well will not require treatment prior to discharge. If a subsequently confirmed exceedance of the operational control criteria is identified, treatment of water from the extraction well will be resumed.

Operation of an extraction well may be discontinued if ground water from that well meets the adjustment control criteria. If shutdown of the well thereby occurs, the well will be sampled as described above in Section V.A.2a for monitoring wells. If a subsequently confirmed exceedance of the adjustment control criteria or an identified trend of increasing chemical concentrations occurs that is projected to lead to an exceedance of the adjustment control criteria, the extraction well will be reactivated.

If contaminant concentrations in ground water entering an extraction well decrease (confirmed as described in Section V.A.2a for exceedances) to levels below the Table IV-1 evaluation criteria, pulse pumping may be initiated at the discretion of the County. Procedures for pulse pumping, which are protective of human health and the environment, will be provided to the Government Plaintiffs for review and approval.

c. Treatment System -- A water treatment system utilizing air stripping, designed to treat water to comply with the Performance Standards, will be installed. The treatment system design will use data developed during the Phase I pilot program. A facilities plan will be developed by the County and provided to the Government Plaintiffs for review and approval. The County may, at its discretion, select treatment system performance goals which provide a higher discharge water quality than that identified by the Performance Standards. Compliance with applicable air emissions standards is addressed in Section V.D.

In the event that water discharged from the treatment system exceeds the Table IV-1 evaluation criteria, necessary improvements or operational adjustments will be accomplished by the County after review and approval by the Government Plaintiffs. In the event that the treatment system cannot meet the Table IV-1 evaluation criteria for methylene chloride, the Government Plaintiffs may apply less stringent evaluation criteria for this constituent. Indicated exceedances will be confirmed using the same methodology described for monitoring wells in Section V.A.2a.

d. Discharge -- Disposal of treated water will be in a manner that meets the Table IV-1 evaluation criteria. Options include discharge to the Little Spokane River, discharge to Deep Creek, or recharge to the shallow aquifer (either upgradient or downgradient of the interception system). Discharge to Deep Creek and recharge to the shallow aquifer will require the specific approval of the Government Plaintiffs. Plans for the discharge system will be submitted to the Government Plaintiffs for review and approval.

B. <u>Extraction, Water Treatment, and Discharge - East System</u>

1. **Bases for Design --**

a. Performance Standards for Ground Water -- The east ground water extraction system is intended for source control near the landfill site and not as an interception system.

b. Location of the East Source Control System -- The source control extraction system will be located based on information developed during Phase I pilot studies. Important considerations in placement of the extraction system will include concentrations and areal distributions of contaminants in the ground water; and hydrogeologic conditions such as saturated thickness of the aquifer(s), hydraulic conductivity, horizontal and vertical hydraulic gradients, and aquifer boundary conditions.

c. Treatment System -- The treatment system will be designed to meet the Performance Standards at the point of discharge from the treatment system. This design will be based on the maximum anticipated contaminant mass influent rate and treatment efficiency levels demonstrated during Phase I pilot testing. Compliance with applicable air emission standards is addressed in Section V.D.

d. Cost Effectiveness -- Design of the Phase II - East extraction/treatment/discharge system will also consider cost effectiveness. The extraction/treatment/discharge system must meet the Table IV-1 evaluation criteria with respect to treatment and discharge. The County may, at its discretion, either select proven technology or new technologies which more economically attain these criteria. The system plans will be submitted to the Government Plaintiffs for review and approval.

2. Design Components and Bases for Decision--

a. Monitoring -- The east extraction system is intended for source control and not plume interception. Consequently, no performance monitoring is required beyond that which is considered necessary by the County to evaluate treatment efficiency and to demonstrate the cost effectiveness of continued operation of the east system as a Remedial Action component for the lower aquifer(s). Phase I - East monitoring wells will be monitored at the discretion of the County.

In the event that monitoring wells upgradient of the extraction system, and outside its capture zone, show a consistent rise in contaminant concentrations that is likely to result in exceedance of the Table IV-1 evaluation criteria, additional upgradient (as previously defined) monitoring will be accomplished. The County will select the number and location of additional monitoring wells, subject to review and approval by the Government Plaintiffs. The County will determine if existing wells will be used or new monitoring wells will be installed.

The criteria presented in this section (V.B.2a) applies only to monitoring during system operation. This criteria is superseded, once the system is shut off, by the monitoring criteria described in Section X of this Scope of Work.

b. Source Control System -- The County will propose a source control system that includes six or more extraction wells. These wells will be installed to the north and to the east of the landfill site at locations exhibiting elevated contaminant concentrations and adequate hydrogeologic properties for sustained extraction at or near the flow rates set forth in the ROD.

As presently envisioned by the County, the system will include at least three extraction wells to the north and three to the east of the landfill. The locations and flow rates of these wells will be determined by the County from Phase I study data and additional monitoring well data. The design for this system will be provided to the Government Plaintiffs for review and approval.

Based on the following criteria, the County may, at its discretion, expand the source control system beyond six extraction wells: aquifer yield; potential contaminant spreading induced by the addition of extraction wells; impact of increased contaminant mass loading to the treatment facility on meeting the Table IV-1 evaluation criteria; and system redundancy with respect to the west interception system and the objectives of the lower aquifer(s) Remedial Action.

Operation of an extraction well may be discontinued, upon approval of the Government Plaintiffs, if the well is not yielding, on a continuous basis, at least 50 percent (20 gpm) of the average discharge rate described in the ROD. If pumping is terminated for an extraction well, that well may, at the County's discretion, be included in the lower aquifer(s) monitoring program.

If deemed appropriate by the County, extraction wells may be subjected to pulse pumping rather than continuous pumping. Plans for pulse pumping will be submitted to the Government Plaintiffs for review and approval.

If ground water withdrawn by an extraction well meets the Table V-1 operational control criteria for two consecutive quarterly samplings, water from this well will not require treatment prior to discharge. If a subsequently confirmed exceedance of the operational control criteria is identified, treatment of water from the extraction well will be resumed.

Pumping may be discontinued from extraction wells if it is determined by the County, with review and approval by the Government Plaintiffs, that continued operation of the well(s) is no longer cost effective. Cost effectiveness will be evaluated based on the extent to which the extraction well(s) are achieving the system goal of source control, and whether it is cost effective to extract contamination near the source rather than at the west interception system.

c. Treatment System -- A water treatment system utilizing air stripping, designed to treat water to comply with the Performance Standards, will be installed. The treatment system design will use data developed during the Phase I pilot program. A facilities plan will be developed by the Count and provided to the Government Plaintiffs for review and approval. The County, at its discretion, may select treatment system performance goals which provide a higher discharge water quality than that identified by the Performance Standards. Compliance with applicable air emissions standards is addressed in Section V.D.

In the event that water discharged from the treatment system exceeds the Table IV-1 evaluation criteria, necessary improvements or operational adjustments will be accomplished by the County after review and approval by the Government Plaintiffs. Indicated exceedances will be confirmed by follow-up sampling and analysis using the same methodology described for monitoring wells in Section V.A.2.a.

In the event that the treatment system cannot meet the Table IV-1 evaluation criteria for methylene chloride, the Government Plaintiffs may apply less stringent evaluation criteria for this constituent. Indicated exceedances will be confirmed using the same methodology described for monitoring wells in Section V.A.2a.

d. Discharge -- Disposal of treated water will be in a manner that meets the Table IV-1 evaluation criteria. The County will choose the specific means of disposal; options include discharge to the Little Spokane River and recharge at or near the landfill site. The viability of treated water recharge at or near the landfill site will be evaluated by the County and may include consideration of cleanup acceleration resulting from contaminant flushing within the unsaturated zone, and the potential impact of increased contaminant loading on treatment system performance. If this evaluation confirms the viability of recharge, the County will submit a plan to the Government Plaintiffs for their review and approval.

C. Extraction, Water Treatment, and Discharge - West System

1. **Bases for Design --**

a. The goal of the west ground water interception system is to prevent the spread of contaminated ground water downgradient of the interception system. Both the Government Plaintiffs and County recognize that a higher level of protection is appropriate for that portion of the lower aquifer (downgradient of the interception system) within the zone of capture of existing supply wells, than for that portion of the aquifer downgradient of the interception system where contaminants can migrate directly to the Little Spokane River without impacting existing supply wells.

b. Location of the Interception System -- The ground water interception system will be located east of Highway 2 in proximity to the north-south alignment shown in the ROD.

c. Treatment System -- The treatment system will be designed to meet the Performance Standards at the point of discharge from the treatment system. This design will be based on the maximum anticipated contaminant mass influent rate and treatment efficiency levels demonstrated during Phase I pilot testing. Compliance with applicable air emission standards will be addressed during treatment system design in accordance with the provisions of Section V.D.

d. Cost Effectiveness -- Design of the Phase II interception/treatment/discharge system will also consider cost effectiveness. The minimum level of effort required for the west interception system is prevention of the spread of the constituents of concern at concentrations which exceed the evaluation criteria identified in Table IV-1. The treatment and discharge system must meet these evaluation criteria. The County, at its discretion, may either select proven technology or new technologies which more economically attain these criteria. The system plans will be submitted to the Government Plaintiffs for review and approval.

2. **Design Components and Bases for Decision--**

a. Monitoring -- A monitoring program will be instituted to evaluate the Phase II interception system performance. Two sets of monitoring wells will be included in the west interception system performance monitoring program. The first set (set A) of monitoring wells will be utilized for evaluation of interception system performance for those portions of the lower aquifer within the capture zone of existing supply wells located downgradient of the interception system, and will consist of three monitoring wells located directly upgradient of the existing supply wells. The second set (set B) of monitoring wells will be utilized for evaluation of interception system performance for those portions of the lower aquifer not directly impacting the water quality of the existing supply wells, and will include three monitoring wells located downgradient of the interception system. Two additional monitoring wells placed at the outboard limit of the interception system will also be included in the interception system monitoring program. These outboard wells may also serve as extraction wells, if adjustment control criteria (as described in Section V.C.2b) are exceeded during monitoring.

The monitoring system may, at the discretion of the County, include new wells or, if appropriate, wells installed as part of the Phase I program. Phase I wells not included in the interception system performance monitoring program will be monitored at the County's discretion. A more extensive monitoring system may be proposed by the County if they determine that additional ground water monitoring is appropriate. Plans for additional monitoring would be provided to the Government Plaintiffs for review and approval.

Quarterly sampling and analysis will be conducted for each of the interception system monitoring wells, for the four indicator compounds shown in Table V-1 and discussed in Section

V.A.2a, except the performance monitoring wells (sets A and B) will initially be sampled more frequently as subsequently described in Section V.C.2b. Quarterly sampling for each well will be continued until no exceedance of the Table V-1 adjustment control criteria is identified for twelve consecutive quarters. In the event that, for a particular well, no exceedances occur during the twelve quarters, sampling will be reduced to an annual frequency for the next two years. If no exceedances have been identified during this five-year period, the County will determine whether continued monitoring is appropriate based on the need to assure longer-term protection of purveyor wells near the site. If no exceedances occur in a particular monitoring well (or converted extraction well, as described in Section V.C.2b), but an increasing trend in concentrations is identified that would likely result in exceedance of the adjustment control criteria, the County will implement a longer-term sampling and analysis program that assures the protection of human health and the environment.

In the event that a single exceedance of the adjustment control criteria occurs, a follow-up sampling will be accomplished. An exceedance will be confirmed if concentrations exceeding the adjustment control criteria specified in Table V-1 are identified in three consecutive samples collected at two-week intervals. If an exceedance is confirmed, the Government Plaintiffs may require installation of additional monitoring wells or implementation of more extensive monitoring of existing wells. Further, the County will submit, for the Government Plaintiffs' review and approval, a program to address the exceedance. This program will include measures to protect human health and the environment.

The criteria presented in this section (V.C.2a) applies only to monitoring during system operation. While the interception system is shut off and on standby status, this system operation criteria is superseded by the monitoring criteria described in Section X of this Scope of Work.

b. Interception System -- In order to meet the goals identified in Section V.A.1a, the County will accomplish the following:

- Conduct the Phase I pilot studies to obtain the needed aquifer characteristics for designing an interception system.
- Complete a preliminary design engineering report detailing the most probable aquifer characteristics, design parameters and project costs. The system will be designed utilizing capture zone analysis to achieve overlapping cones of depression, and such that the total pumping capability of the interception well system is sufficient to intercept the plume to the extent described in this section. Selection of pumping test methodologies and capture zone analysis will be subject to the review and approval of the Government Plaintiffs.

These extraction wells will be installed east of Highway 2 in proximity to the north-south alignment shown in the ROD. Extraction wells will be installed in succession from the center to the outermost limits of the plume. The spacing of the wells will be determined by the County based on hydrogeologic and chemical data. Extraction wells will be installed until the ground water at the outermost limits of the system is below the adjustment control criteria. The outermost wells will be used for interception system monitoring and will be constructed such that conversion to extraction wells is possible if exceedances of adjustment control criteria are subsequently identified. If an outboard monitoring well is converted to an extraction well, an additional monitoring well (constructed for possible conversion to an extraction well) will be constructed to the outside of the converted monitoring/extraction well.

Interception system design criteria will be based on the Table I-1 Performance Standards. Operational and adjustment criteria will be developed based on Table IV-1 evaluation criteria and observed interception system efficiency during the early stages of Phase II.

The design criteria will serve as a guide for the use of the capture analysis referred to in this section. The basis for design of that portion of the west system that intercepts ground water migrating into the capture zone(s) of existing downgradient supply wells will be that the average concentrations of the constituents of concern in the existing supply wells downgradient of the interception system are predicted to be no greater than 15 percent of the Table I-1 Performance Standards based on capture zone analysis. The remainder of the system will be designed such that the average concentrations of constituents of concern in the lower aquifer downgradient of the interception system will be no greater than 50 percent of the Table I-1 Performance Standards.

Commencing at a mutually agreed-upon time following startup of the interception system, the two sets (A and B) of downgradient performance monitoring wells will be sampled monthly (for Table V-1 constituents) for two years, or some other mutually agreed-upon length of time. Based on statistical analysis of the chemical data from these wells, separate baseline concentrations[3] will be identified for each set (A and B) of downgradient performance monitoring wells for each Table V-1 constituent. The baseline concentrations for each set (A and B) of monitoring wells will be equal to the average of the time- averaged concentrations in the

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(3) If the resulting concentration is below the Practical Quantitation Limit (PQL) for a Table I-1 constituent, the PQL reported for EPA Method 8010 (USEPA, "Test Methods for Evaluating Solid Waste," SW-846, 3rd Ed. 1986) will be used as the baseline concentration for that constituent.

three performance monitoring wells associated with that set and, if appropriate, may include vertical averaging for nested wells or well clusters, after the data associated with the expected gradual changes following startup are eliminated.

Operational control criteria for the west interception system will be developed for the appropriate Table V-1 indicator compounds (1,1-TCA and 1,1-DCA) and will only apply to that portion of the system intercepting ground water migrating towards existing downgradient supply well capture zones and will be equal to the lesser of: 1) the baseline concentration based on the "A" set of monitoring wells plus 15 percent of the Table IV-1 evaluation criteria or 2) 30 percent of the Table IV-1 evaluation criteria. If, after confirmation (as defined in Section V.A.2a) the average concentration in the "A" set of performance monitoring wells exceeds the operational control criteria, the County will re-evaluate the operation of the interception system. Should this re-evaluation indicate adjustments to the system are appropriate, the County will submit a proposal for interception system adjustment to the Government Plaintiffs for review and approval. Adjustments may include increasing pumping rates (for one or more wells), or other adjustments to the existing system considered appropriate for improving contaminant interception efficiency.

Adjustment control criteria for the west interception system will be developed for the Table V-1 indicator compounds and will be equal to the lesser of: 1) the baseline concentration (for set "A" or "B monitoring wells", as appropriate) plus 50 percent of the Table IV-1 evaluation criteria or 2) 65 percent of the Table IV-1 evaluation criteria.

If after confirmation (as defined in Section V.A.2a), the average concentration in either the "A" or "B" sets of downgradient monitoring wells exceeds the adjustment control criteria for two consecutive quarters (or some other mutually agreed upon timeframe that will better allow reflection of system adjustments in downgradient monitoring wells) following system adjustment (as described previously for operational control criteria exceedances), the interception system will be modified if applicable. Additionally, the interception system will be modified if any Set "A" individual downgradient performance monitoring well exceeds the Table IV-1 evaluation criteria for two consecutive quarters (or other time period, as described above). Modifications may include increasing pumping rates (for one or more wells), adding extraction wells to the system, or other methods of correcting interception system deficiencies. The County will submit a proposal for interception system modification to the Government Plaintiffs for review and approval.

In addition to the operation and adjustment control criteria described above, should any set "A" downgradient performance monitoring well, following the development of baseline concentrations, exhibit anomalous concentrations or trends in concentrations inconsistent with effective interception system performance (such as an increasing trend in concentration projected to lead to a long-term exceedance of the Table V-1 adjustment control criteria), the County will evaluate the operation of the interception system. This evaluation will address the potential cause(s) of the anomaly and possible system adjustments or modifications (if appropriate), and will be presented to the Government Plaintiffs in a written report for their review within 60 days of the evaluation.

If it is determined by the County that an exceedance of the above criteria is the result of supply well interference with the interception system, adjustment to, or modification to, the system may include elimination of the interference. Elimination of the interference may require either partial or complete cessation of supply well use. The County will attempt to negotiate a settlement with the well owner. If an equitable agreement cannot be reached between the County and the well owner, the Government Plaintiffs will use their statutory authority to seek termination of usage for the interfering well.

Based on cost effectiveness or a determination by the County that acceleration of the cleanup is appropriate, the County may, at its discretion, propose additional upgradient extraction wells. Any such proposal will be submitted to the Government Plaintiffs for review and approval.

If ground water withdrawn by an extraction well meets the operational control criteria for two consecutive quarterly samplings, water from this well will not require treatment prior to discharge. If a subsequently confirmed exceedance of the operational control criteria is identified, treatment of water from the extraction well will be resumed.

Operation of an extraction well may be discontinued if ground water at that well meets the adjustment control criteria. If shutdown of the well thereby occurs, the well will be sampled as described above in Section V.C.2a for monitoring wells. If a subsequently confirmed exceedance, or an identified trend of increasing chemical concentrations occurs that can be projected to lead to an exceedance, of the adjustment control criteria at downgradient supply wells, reactivation of the extraction well may be necessary.

If concentrations in ground water entering an extraction well decrease (confirmed as described in Section V.B.2a for exceedances) to levels below the Table IV-1 evaluation criteria, pulse pumping may be initiated at the discretion of the County. Procedures for pulse pumping, which are protective of human health and the environment, will be provided to the Government Plaintiffs for review and approval.

c. Treatment System -- A water treatment system utilizing air stripping, designed to treat water to comply with the Performance Standards, will be installed. The treatment system design will use data developed during the Phase I pilot program.

If water discharged from the treatment system exceeds the Table IV-1 evaluation criteria, necessary improvements or operational adjustments will be accomplished by the County after review and approval by the Government Plaintiffs. In the event that the treatment system cannot meet the Table IV-1 evaluation criteria for methylene chloride, the Government Plaintiffs may apply less stringent evaluation criteria for this constituent. Indicated exceedances will be confirmed using the same methodology described for monitoring wells in Section V.C.2a.

A gravity air stripping system, which takes advantage of the elevation drop between the bluff near Highway 2 and the Little Spokane River may be installed, if Phase I pilot system test results indicate this method will meet Table IV-1 evaluation criteria. If, based on the criteria identified in Section V.D., off-gas treatment is required, a conventional air stripping system will be installed.

d. Discharge -- Disposal of treated water will be to the Little Spokane River. Discharge water will meet the Table IV-1 evaluation criteria. Plans for the discharge system will be submitted to the Government Plaintiffs for review and approval.

D. Air Emissions Abatement

The necessity for air stripping tower off-gas abatement during Phase II will be evaluated based on the assessment of lifetime cancer risk for carcinogenic compounds, and on hazard indices for non-carcinogenic compounds, in accordance with methods described in the Superfund Public Health Evaluation Manual (EPA 54011-86/060, 1986). Phase I data, and the criteria described below, will be used in these evaluations during Phase I. Additional data developed during the early stages of Phase II will be used to reassess the Phase I evaluation. If the County can demonstrate to the Government Plaintiffs that the lifetime cancer risks and the hazard indices are below 10^{-6} and 1, respectively, off-gas treatment will not be required.

A preliminary analysis of air emissions for the Table I-1 compounds has been accomplished using a standard Gaussian plume model and 100 percent transfer efficiency (water to air media). The analysis considered receptor distances of 500 and 1000 feet, a stack height of 40 feet, and assumed that all water treatment would be accomplished at one location. The analysis used National Weather Service Wind Data for the Spokane International Airport and an initial mass flux to the stripping towers equal to that arrived at from the projected influent concentrations and pumping rates identified in the RI/FS. It was further assumed that the total mass of each constituent removed during the cleanup could be equal to as much as 5 times the mass of each constituent identified as being present in the ground water, based on the data contained in the RI/FS.

Based on these assumptions, the model predicts that for the carcinogenic and potential carcinogenic compounds (TCE, DCE, PCE, and MC) the summation of the incremental increases in cancer risk for the individual compounds is below 10^{-6} (1 in 1 million), and the hazard index summation for all Table I-1 non-carcinogenic compounds is below 1. Because the analysis utilized some assumptions which have not been fully confirmed at the site, the following verification steps will be taken:

1. Air monitoring and modeling will be conducted during Phase I to confirm the wind speed, wind direction, and applicability of the Gaussian model. If the County determines that air emissions can be better analyzed using a different model, the proposed model, and rationale for its use, will be submitted to the Government Plaintiffs for review and approval.

2. Phase I and Phase II data will be evaluated to estimate the total mass of the six indicator constituents present in the ground water.

3. Measurements will be made during Phase I and the early stages of Phase II to identify the mass flux of the six indicator constituents to the stripping tower(s). These data will be compared with the flux rates identified in the RI/FS.

If the new information supports the initial analysis, air stripping tower off-gas abatement will not be required.

If the Phase I data does not support the initial analysis, the County will re-examine the need for Phase II off-gas treatment. This re-examination will be accomplished prior to Phase II and presented to the Government Plaintiffs for their review and approval. Should this re-examination identify that off-gas treatment is necessary on either a temporary or permanent basis, based on the criteria described above, the County will make the appropriate adjustments to incorporate carbon absorption, or some other agreed-upon method of air emissions abatement, in the stripping tower design for Phase II.

Air emissions abatement will be re-evaluated during the early stages of Phase II (within a year of Phase II startup). If the Phase II data do not support the Phase I analysis, the County will re-examine the need for off-gas treatment within 60 days of re-evaluation and submit such re-examination to the Government Plaintiffs for review and approval. Should this re-examination identify that off-gas treatment is necessary on either a temporary or permanent basis, based on the criteria described above, the County will retrofit the stripping tower(s) with carbon absorption, or some other agreed-upon method of air emissions abatement. Alternately, should this re-examination identify that off-gas treatment is no longer necessary (if required following Phase I analysis), off-gas treatment may be terminated.

APPENDIX B

Groundwater Flow Model Description

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

The purpose of this Appendix is to describe the groundwater flow modeling procedures used for Phase II design. The models were developed to aid in the design of the Phase II groundwater interception and extraction systems, and to improve understanding of the hydrogeologic system at the site. The groundwater flow models were used to simulate behavior of the aquifer systems under steady-state pumping and non-pumping conditions. The steady-state pumping simulations were used to select extraction well locations, and to estimate extraction well pumping rates and the resulting capture zones. The groundwater flow models were also used in conjunction with the solute transport model, described in Appendix C, to estimate influent concentrations for design of the treatment system.

1.1 METHODOLOGY

Data collected during Phase I were used to characterize site hydrogeologic conditions (Landau Associates 1991). These data were used to develop (separate) groundwater flow models of the Upper Sand/Gravel Aquifers (Upper Aquifer) and Lower Sand/Gravel Aquifer (Lower Aquifer), using the MODFLOW computer code (McDonald and Harbaugh 1988). The process used to develop the groundwater flow models is summarized below:

- Development of a conceptual model. The domain of the major hydrogeologic units for the model was conceptualized, and the nature and extent of the units were characterized. Finite-difference model grids were developed for the systems.

- Data compilation and preparation. Data required to define the model parameters and boundary conditions were compiled. The point data were converted into a continuous field format required for the model using a geographic information system (GIS), spreadsheet software, and line editors. Expected ranges for boundary fluxes and conductances, and other model parameters, were estimated and target data for calibration were selected.

- Model calibration. Initial model parameters and boundary conditions were adjusted so that the simulated heads compare within acceptable limits to measured values at select points. Sensitivity of the model to boundary conditions and other model parameters was assessed during calibration by varying these parameters beyond expected ranges.

- Pumping Scenarios. Extraction well locations and pumping rates were varied to get complete capture between wells and over the plume width upgradient of the interception system. Particle tracking was used to evaluate interception system capture-zone characteristics.

2.0 CONCEPTUAL MODEL

2.1 AQUIFER SYSTEMS

The groundwater flow system in the modeled area was conceptualized as two aquifers, the Upper Aquifer and the Lower Aquifer, separated by the Lacustrine Aquitard and underlain by a basal confining unit. A generalized east-west geologic profile is shown on Figure B-1.

Additional water bearing units of limited productivity and limited areal extent occur to the east of the modeled area. Groundwater extraction is not planned for these units (except on a limited basis in the immediate Landfill vicinity), and were not characterized as separate units in the models. Instead, these units were modeled as recharge, primarily to the Lower Aquifer.

The Lacustrine Aquitard acts as a leaky confining layer for the Upper Aquifer, and as a recharge boundary for the Lower Aquifer via leakage. However, the Lacustrine Aquitard does contain significant water bearing sands, which are locally in direct hydraulic connection with the Upper Aquifer.

2.2 HYDROLOGIC BOUNDARIES

2.2.1 Upper Aquifer

The Upper Aquifer is truncated to the west by a bluff overlooking the Little Spokane River Valley. Discharge occurs along this bluff in the form of springs and, possibly, subsurface flow. Groundwater contour elevations (Figure B-2) suggest that groundwater flow in the Upper Aquifer is, primarily, from north to south in the aquifer, indicating a recharge boundary to the north and a discharge boundary to the south. Data for the eastern boundary of the Upper Aquifer is limited, except in the immediate vicinity of the Landfill where the Lacustrine Aquitard pinches out and the Upper Aquifer appears to discharge to the Lower Aquifer. Based on the groundwater contours, there appears to be some recharge to the Upper Aquifer from the east, particularly immediately southeast of the Landfill. Deflection of groundwater contours to the southeast about 1 mile south of the Landfill suggests that a discharge point may occur in this direction. Hydrogeologic data indicate this change in flow direction may result from an apparent high permeability trough oriented parallel to the flow direction (Landau Associates 1991).

Recharge for the Upper Aquifer also occurs via infiltration from precipitation. Long-term monitoring of wells in the Upper Aquifer shows minimal seasonal fluctuation (Landau Associates 1991, Figure ER-4.16). This lack of seasonal fluctuation may be due to attenuation of seasonal variations in precipitation by the depth of the aquifer (approximately 90 ft below ground surface), or may be the result of recharge from an unidentified source.

The lower boundary of the Upper Aquifer is formed by the Lacustrine Aquitard, although water-bearing sands in the upper portions of the aquitard appear to be (locally) in direct hydraulic connection with the Upper Aquifer. Overall, the Lacustrine aquitard serves as a leaky discharge boundary.

2.2.2 Lower Aquifer

Groundwater flow in the Lower Aquifer is generally from east to west (Figure B-3). To the east, the Lower Aquifer thins and disappears where it abuts against the Latah Formation (a low permeability unit rising to the east). Groundwater originating to the east of the Lower Aquifer flows primarily along the top of the Latah Formation and enters the Lower Aquifer. The Lower Aquifer also receives recharge from the Upper Aquifer (where the Lacustrine Aquitard pinches out), and from leakage through the Lacustrine Aquitard.

Estimates of groundwater flow in the Lower Aquifer compared to hydraulic data from studies of the Little Spokane River [Washington State Department of Ecology (Ecology), 1975] suggest that discharge from the Lower Aquifer is to the Little Spokane River (see section 5.2 of this Appendix). Deflection of groundwater contours, along with limited boring logs, suggest that greater discharge to the Little Spokane River occurs along the river meander west-northwest of the Landfill.

2.3 HYDRAULIC PROPERTIES

The hydraulic conductivity of the Upper Aquifer was estimated to be from 530 to 640 ft/day, based on pumping test data from Pilot Extraction Well CP-S1 (Landau Associates 1991). This well is located within a northwest-southeast trending apparent trough of greater saturated thickness in the Upper Aquifer. It is likely that the trough consists of coarser material than elsewhere in the Upper Aquifer, suggesting that the hydraulic conductivity is higher within the trough as well. The saturated thickness of the Upper Aquifer ranges from less than 1 ft to greater than 19 ft (Landau Associates 1991, Figure ER-4.14).

Hydraulic conductivity of the Lower Aquifer was estimated from pumping tests at Pilot Extraction Wells CP-E1 and CP-W1, and was estimated to range from 100 to 230 ft/day. The hydraulic conductivity is estimated to be higher at CP-W1 than at CP-E1. The saturated thickness of the Lower Aquifer ranges from 0 ft east of the Landfill to over 220 ft to the west (Landau Associates 1991, Figure ER-4.17).

The vertical hydraulic conductivity of the Lacustrine Aquitard was estimated at several locations using drilling logs and representative hydraulic conductivities for the identified soil types, as well as lab permeabilities published in the Remedial Investigation (Golder Associates 1987). The vertical hydraulic conductivity was estimated to range from 0.02 to 4E-4 ft/day. The thickness of the Lacustrine Aquitard ranges from 0 to greater than 150 ft (Landau Associates 1991, Figure ER-4.12).

3.0 COMPUTER CODE DESCRIPTION

The computer code MODFLOW (McDonald and Harbaugh 1988) was used to simulate groundwater flow in the modeled areas of the Upper and Lower Aquifers. MODFLOW is a numerical finite-difference code that represents groundwater flow by a set of partial differential equations. The code consists of a main program and a series of independent subroutines (called modules), which provide flexibility for modification of the model as additional information on the modeled system becomes available.

Groundwater flow is simulated using a block-centered finite-difference approach. Spacing of the block-centered grids can be varied across the modeled area. Modeled layers can be simulated as confined, unconfined, or a combination of confined and unconfined. The code allows for the simulation of heterogeneities and external stresses, such as flow to and from wells, areal recharge, flow to drains and through riverbeds, and leakage between layers.

Boundaries can be represented as specified (constant) head (type 1), specified (constant) flux (type 2), or head-dependant (type 3). In MODFLOW, head-dependant boundaries can be represented with river, drain, or general head boundaries, all of which require elevation data and conductance terms. The drain package only allows flow to the drain (out of the model), whereas, flow for the general head and river packages can be into or out of the model. Flow calculated for the head-dependant boundaries are proportional to the head difference; however, for the river package a maximum flux from the river is calculated based on specified elevations.

MODFLOW is one of the most widely used groundwater flow codes and has been shown to be an accurate and reliable tool for simulation of complex aquifer systems, such as those encountered in the vicinity of the Landfill.

4.0 GROUNDWATER FLOW MODEL SET-UP

Separate models were developed to simulate groundwater flow in the Upper and Lower Aquifers. Two scenarios were used for each of the models developed. The two scenarios represent anticipated upper and lower bound flow conditions, and were developed to account for potential variation in aquifer properties and the uncertainty created by unknowns and assumptions required for model development.

4.1 MODEL DOMAIN

The domain of the finite-difference grid selected for the Upper Aquifer model is shown on Figure B-4. The model covers an area 11040 ft x 18480 ft and is defined by a grid consisting of 20648 cells (116 columns x 178 rows). A variable grid spacing was used, with tighter spacing (40 ft) used in the area of the proposed South Interception System extraction wells to provide better resolution for capture-zone analysis. Elsewhere in the model, 120 ft grid spacing was used.

The domain of the grid used for the Lower Aquifer model is presented in Figure B-5. The model covers an area 11040 ft x 16000 ft and is defined by a grid consisting of 17864 cells (116 columns x 154 rows). The high transmissivity of the Lower Aquifer in the vicinity of the extraction wells (and, thus, greater well spacing) allowed the use of a constant grid spacing of 120 ft throughout the model domain.

In both models, the model domain was chosen to minimize the impact of model boundaries on drawdown during pumping simulations. This required an enlargement of the model domains during calibration. Although drawdown does extend to some model boundaries, the impact on modeling results appears to be minimal.

4.2 MODEL BOUNDARY CONDITIONS

4.2.1 Upper Aquifer

Model boundary conditions for the Upper Aquifer are shown on Figure B-6. The bluff along the western edge of the model was simulated with a no-flow boundary, and the springs along the bluff were simulated as head-dependant boundaries (drains). To the north, a constant-head boundary provides recharge. A head-dependant boundary (general head) was used to simulate discharge at the model's southern boundary.

Discharge from the Upper Aquifer to the east of the Landfill, where the Lacustrine Aquitard pinches out, was simulated as a head-dependant boundary (drains). Elsewhere along the eastern boundary, head-dependant boundaries (general head) provided recharge. Heads were selected along the southern portion of the eastern boundary so that recharge only occurred during pumping. Discharge out the southeast boundary was simulated as a head-dependant boundary (drains).

The Lacustrine Aquitard is represented implicitly in the Upper Aquifer model by a field of vertical conductance (VCONT) terms, which are the estimated vertical hydraulic conductivities of the Lacustrine Aquitard divided by the aquitard thickness. These VCONT terms were estimated to range from 1E-5 to 1E-7 day^{-1}, based on an estimated vertical hydraulic conductivity of 4E-4 ft/day and estimated thicknesses of 30 to 100 feet for the fine-grained aquitard units (silt or clay).

4.2.2 Lower Aquifer

Model boundary conditions for the Lower Aquifer are shown on Figure B-7. The eastern and southeastern boundary for the Lower Aquifer was simulated as a constant flux (recharge) boundary. The northern and southwestern boundaries were simulated as no flow. The western boundary was simulated as head-dependant (general head) for the two scenarios presented, but was also simulated as constant-head and constant-flux during model calibration. Leakage from the Lacustrine Aquitard (into the Lower Aquifer) was simulated as areal recharge at a rate of 0.14 to 10 ft^3/day per cell, depending on aquitard thickness.

Discharge from the Lower Aquifer to the Little Spokane River was simulated using the MODFLOW river package. River stage elevations were estimated from topographical maps and from surveyed elevations west of the Landfill.

4.3 MODEL HYDRAULIC PARAMETERS

4.3.1 Upper Aquifer

The Upper Aquifer was initially simulated as a confined aquifer to minimize potential model stability problems due to limited saturated thickness. Once calibration was approached, the Upper Aquifer model was converted to unconfined conditions, which required the input of a hydraulic conductivity (K) and saturated thickness field (input as a bottom of aquifer elevation field). Modeled K and saturated thickness fields for the Upper Aquifer are shown on Figures B-8 and B-9, respectively.

The modeled area for the Upper Aquifer was subdivided into an area of high K in a zone of greater saturated thickness (representing the apparent trough), and an area of lower K outside of the apparent trough. Upper and Lower K values of 530 and 410 ft/day were used for the lower bound flow scenario, while K values of 640 and 500 ft/day were used for the upper bound flow scenario (Table B-1).

4.3.2 Lower Aquifer

The Lower Aquifer was simulated as a confined aquifer. Hydraulic parameter input to the model consisted of a transmissivity field. The transmissivity field was developed as a product of the estimated K and saturated thickness of the aquifer. The Lower Aquifer was subdivided into high and low K zones, as shown on Figure B-10. The higher K value was assigned to a zone of greater saturated thickness to the west of the Landfill based on the higher estimated K values from the CP-W1 pumping test, than from the CP-E1 pumping test (Landau Associates 1991). K values used for upper bound flow model simulations were 200 and 270 ft/day (for low and high K zones, respectively), while K values of 110 and 180 ft/day were used for lower bound flow simulations (Table B-1).

Little Spokane River bed conductances were estimated by assuming that river conductance is controlled by the extension of the Lacustrine Aquitard beneath the river. Boring logs from Wells CD-40, CD-41, CD-42, and CD-43 were used to extrapolate the aquitard bottom elevation to the river vicinity. The difference between the bottom of the Lacustrine Aquitard and the bottom of the Little Spokane River was used to estimate the thickness of the river bed. An assumed river bed vertical K of 0.7 ft/day provided a range of 150 to 1500 day^{-1} for the river bed conductance input to the model.

For boundaries impacted by drawdown, the boundary effects were minimized by using head-dependant (general head) boundaries. Conductances were estimated using K values representative for the aquifer. Head elevations for the boundary in the southeast portion of the Upper Aquifer model were selected so the boundary would behave as no flow during static (nonpumping) simulations, but provide water during pumping simulations. Elsewhere, groundwater elevations were based on extrapolated gradients from Phase I groundwater elevation data.

Due to the long-term nature of remediation, the models were run steady-state rather than transient (time variable). As a result, no aquifer storage values were needed.

5.0 MODEL CALIBRATION

5.1 CALIBRATION TARGETS

The model static (nonpumping) head elevations were calibrated to Phase I measured groundwater elevations for the Upper and Lower Aquifers. The wells used as calibration points are shown on Figures B-4 and B-5 for the Upper and Lower Aquifer models, respectively.

Estimated groundwater flux was also used as a calibration target. Groundwater flux across a representative aquifer cross section was estimated using Darcy's Law (Q=KiA), and compared to the model groundwater flux across the associated boundary.

5.2 RESIDUALS AND FLUXES

Model calibration continued until residual head values (the difference between observed and predicted heads) were within acceptable limits. Acceptable residuals vary from site to site, and were considered sufficient for this study when residual head values were generally within about 1 ft in the vicinity of the interception or extraction system. Head matches near some model boundaries were more difficult to achieve (and of lesser significance), and the tolerances were, accordingly, greater.

Residual head values are presented in Table B-2 for the Upper Aquifer, and in Table B-3 for the Lower Aquifer. In most cases, the head matches were within one-half foot in the areas of interest. This degree of accuracy was particularly important for the Lower Aquifer, because the hydraulic gradient is extremely flat in the area of interest, and higher residuals could result in significantly erroneous gradients, thereby reducing the accuracy of the predicted capture zone. Despite a relatively close head match, the model-simulated gradient for the Lower Aquifer in the vicinity of the West Interception System was flatter than the observed gradient by approximately 30 percent.

Predicted fluxes across model boundaries were monitored during calibration, and compared to fluxes estimated from Phase I data. Groundwater flux for the Upper Aquifer was estimated for the southern portion of the model domain. As shown in Table B-4, model-simulated discharge (when adjusted for additional recharge for the area between the model boundary and the estimated flux line) agrees well with the estimated value.

Groundwater flux estimated from Phase I data for the Lower Aquifer to the west compares well with model-predicted river discharge, and suggests that the Lower Aquifer discharges primarily (or entirely) to the river. The model-predicted flux to the Little Spokane

River agrees well with the estimated Lower Aquifer flux and published data. The model-predicted-flux, and flux estimated from Phase I data, are somewhat lower than the estimated flux from the published data (Ecology 1975). This difference may result (in part) from Upper Aquifer discharges along the bluff, or variations between actual conditions and the assumed conditions used to estimate groundwater flux. The estimated and model-predicted fluxes for the Upper and Lower Aquifers are shown in Table B-4.

5.3 SENSITIVITY

The influence of model boundaries and aquifer parameters upon model predictions were assessed during calibration. This was achieved by noting the changes in predicted heads caused by variations in model parameters. In most cases, parameters were varied within expected ranges, but in some instances the parameters were changed by an order of magnitude to evaluate their relative affect.

Parameters adjusted during model calibration included the aquifer parameters (hydraulic conductivity or transmissivity), the conductance values for the head dependent boundaries, and areal recharge and discharge (precipitation and aquitard leakage). The boundary conductances were adjusted to calibrate model-predicted heads to measured heads (for the selected flow scenario), but kept within reasonable ranges. In some instances the boundaries were changed as well. The western boundary for the Lower Aquifer was simulated as a head dependant boundary (general head), a constant head boundary, and a constant flux boundary, and very little difference in model-predicted heads or groundwater flux were observed.

The models were calibrated to the upper and lower bound hydraulic conductivity (or transmissivity) values described in Section 4.3 of this Appendix. However, sensitivity analyses were performed using values beyond these ranges. Transmissivities for the Lower Aquifer model were set at twice the upper bound value, and hydraulic conductivities for the Upper Aquifer model were set at values up to 25 percent below the lower bound value from the Phase I pumping test. In both cases, capture was achieved with the proposed well configurations, and the flow site was within the identified operational range of 600 to 1,600 gpm.

The models were most sensitive to changes in hydraulic conductivity and to changes in conductances at the boundaries. The models were least sensitive to precipitation in the case of the Upper Aquifer, and recharge from the Lacustrine Aquitard for the Lower Aquifer model.

5.4 VERIFICATION

Model verification data, which commonly consists of pumping data, are limited. Drawdown data from the Pilot Extraction Well CP-W1 Phase I pumping test for the Lower Aquifer indicate a recharge source, believed to be the Lacustrine Aquitard. However, the pumping test was too short to achieve true steady-state conditions, which would only occur after the water being removed from storage in the aquitard was depleted. Thus, the data could not be used for model verification.

The pumping test in the Upper Aquifer at Pilot Extraction Well CP-S1 resulted in limited drawdown at the observation wells. However, transient runs were completed for the Upper Aquifer model, and a satisfactory match between model-predicted and observed drawdown at the (b) (6) well was achieved.

Because verification data were limited, the calibrated models do not provide unique solutions. However, the sensitivity analyses performed, utilizing variable boundary conditions and aquifer parameters, appear to adequately compensate for available verification data. Verification data will be available subsequent to startup of the Phase II remedial action, and the models can be verified (if needed) using these data.

6.0 CAPTURE ZONES SIMULATIONS

6.1 PUMPING SIMULATIONS

The calibrated Upper and Lower Aquifer models were used for design and simulation of the proposed Phase II interception and extraction systems. Initial extraction well placement and withdrawal rates were selected using an analytical model. Extraction well locations and withdrawal rates were refined using the calibrated groundwater flow models previously described. Contaminant capture was evaluated using the particle tracking method described in Section 6.2.

Pumping simulations were performed for lower and upper bound flow scenarios for the Upper and Lower Aquifer models. The lower and upper bound flow scenarios result in minimum and maximum pumping rates required to achieve capture for the Phase II interception systems. The South Interception System addresses capture in the Upper Aquifer. The West Interception System, with assistance from the East Extraction System, addresses capture in the Lower Aquifer.

Based on the following equation (Javandel and Tsang 1986), the pumping rate required for capture is directly proportional to the regional flow velocity (and, thus, the gradient):

$$Y = \frac{nQ}{2BU}$$

where:

Q = Pumping rate
n = Number of pumping wells
B = Aquifer thickness
U = Regional flow velocity
Y = Width of capture zone

As a result, the maximum pumping rates for the Lower Aquifer extraction wells (West and East Systems) were increased by 30 percent to compensate for the approximate 30 percent flatter modeled (than observed) gradient in the Landfill vicinity (as described in Section 5.2).

Estimated pumping rates required for capture are presented in Table B-5. Predicted drawdown contours for the Upper and Lower Aquifers are shown on Figures B-11 and B-12 (respectively), and are for the upper bound flow simulations. For each of the models, the drawdown contours were very similar for the upper and lower bound flow scenarios.

6.2 PARTICLE TRACKING AND CAPTURE ZONES

The particle tracking code PATH-3D (S.S. Papadopulos, 1991) was used to aid in capture-zone analysis of the pumping scenarios. The code is designed for use with the output from MODFLOW to predict the movement of particles in the groundwater. Starting particle positions were located in the center of specified cells, and the particle tracking output consisted of a series of coordinates that locate the particles in the model domain for successive time steps.

Particles were placed upgradient and between the extraction wells to estimate the minimum pumping rate required to prevent breakthrough. Extraction well pumping rates were increased until breakthrough between wells did not occur. The maximum extent of cross gradient capture was estimated by placing a line of particles upgradient from the extraction systems across (and beyond) the plume extent of Constituents of Concern. Capture zones were determined from the particle tracking simulations by drawing a line between the first particle that travelled past the end of the extraction system and the last particle captured. Resolution was limited to the width of the cells, or 40 feet for the Upper Aquifer and 120 feet for the Lower Aquifer.

Upper bound flow scenario capture zones estimated from particle tracking simulations are presented on Figures B-13 and B-14 for the Upper and Lower Aquifers, respectively. Capture zones were similar for the two flow scenarios.

7.0 SUMMARY AND CONCLUSIONS

7.1 RESULTS

Both the Upper and Lower Aquifer groundwater model-predicted heads are in general agreement with observed static head elevations. Also, nonpumping aquifer fluxes are in general agreement with estimated fluxes based on available data. Calibration to static conditions was achieved for both models while keeping all model parameters and boundary conditions within reasonable ranges. Sensitivity analyses indicate that the models provide similar results over a range of conditions. Extraction well simulations developed for both (Upper and Lower Aquifer) models provide reasonable ranges of pumping rates required to develop adequate capture zones.

7.2 UNKNOWNS AND LIMITATIONS

The most significant limitation of the models is the lack of verification data. Pumping test results provide an estimate of short-term response of the aquifers to pumping, but do not provide data on how the aquifers behave under steady-state pumping conditions. The development of upper and lower bound flow scenarios is intended to address this limitation.

The interaction of water-bearing sands in the Lacustrine Aquitard with the Upper and Lower Aquifers is likely to result in short-term deviation of actual aquifer response to pumping from the model-predicted response. However, this limitation is not expected to significantly impact long-term performance of the Phase II interception systems.

Other unknowns include a limited knowledge of aquifer heterogeneity and anisotropy characteristics and limited data on aquifer conditions at some of the boundaries, in particular the southeast boundary for each of the models. This is a common limitation resulting from representation of complex systems based on limited point data, and is typically addressed by placing the model boundaries beyond the area of interest. For the systems modeled for this design, the assumptions made to overcome these limitations were reasonable and appear to provide a reasonable approximation of the site hydrogeology. However, the model boundaries may require modification, once Phase II extraction system performance data are available.

In summary, despite the limitations discussed, the models are viable tools for predicting the response of the aquifers to pumping scenarios. There will likely be some variations between predicted and observed aquifer response to pumping, but pumping rates required for capture are anticipated to be between those identified for upper and lower bound flow scenarios. As additional information becomes available during Phase II operations, the models can be furthered refined (if necessary), and can used to provide simulations for operational changes during remediation.

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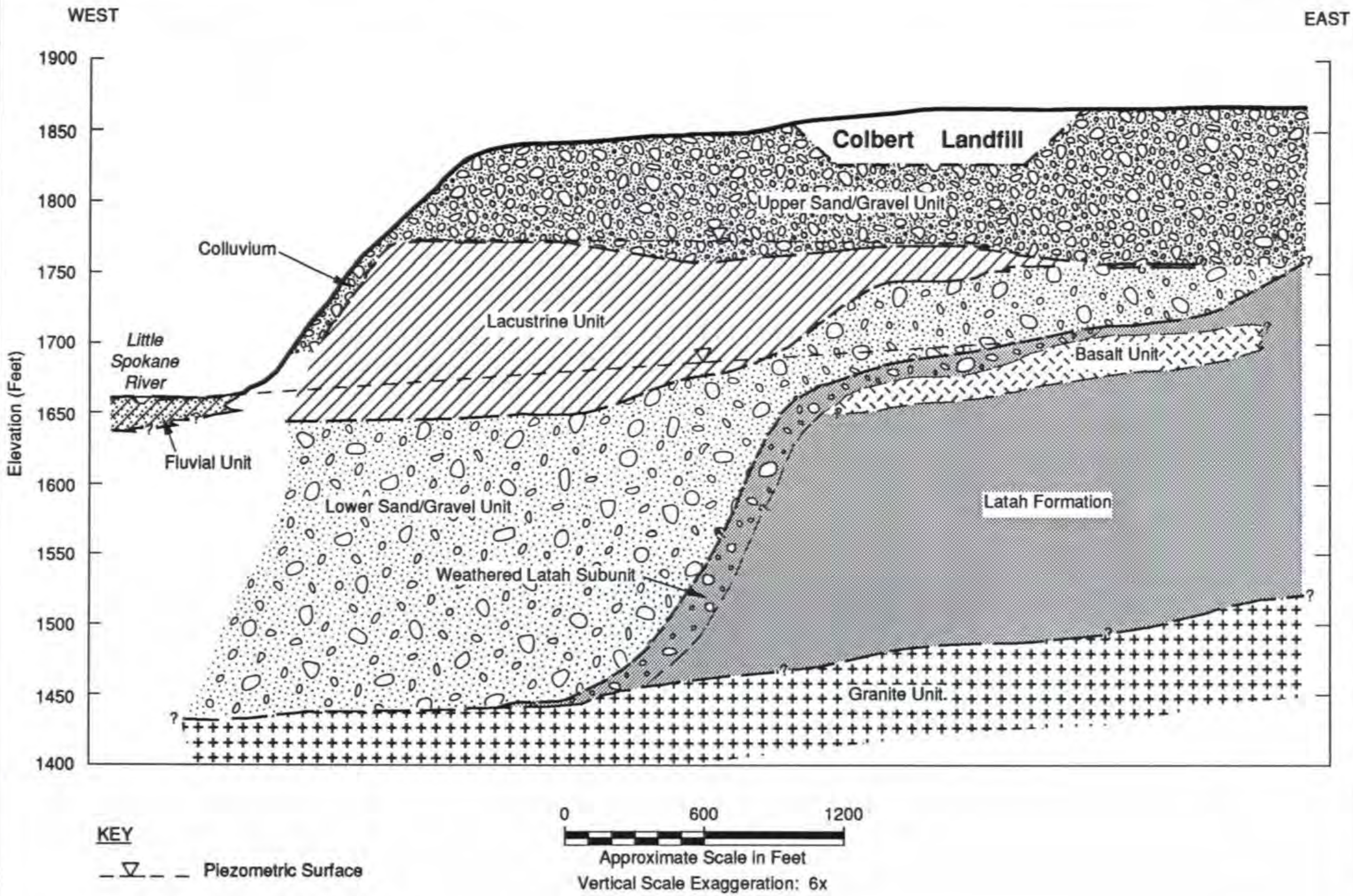
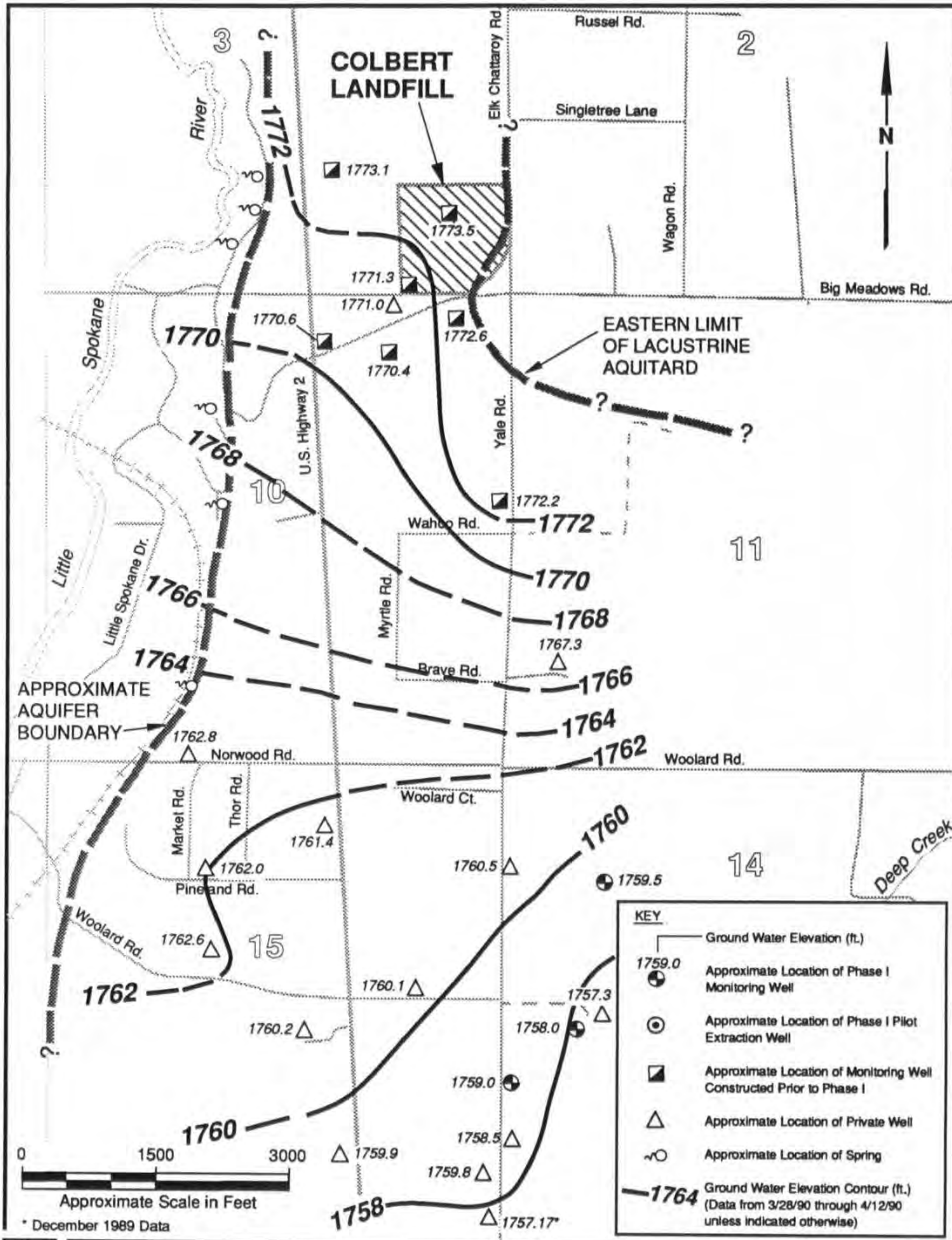


Geologic Schematic

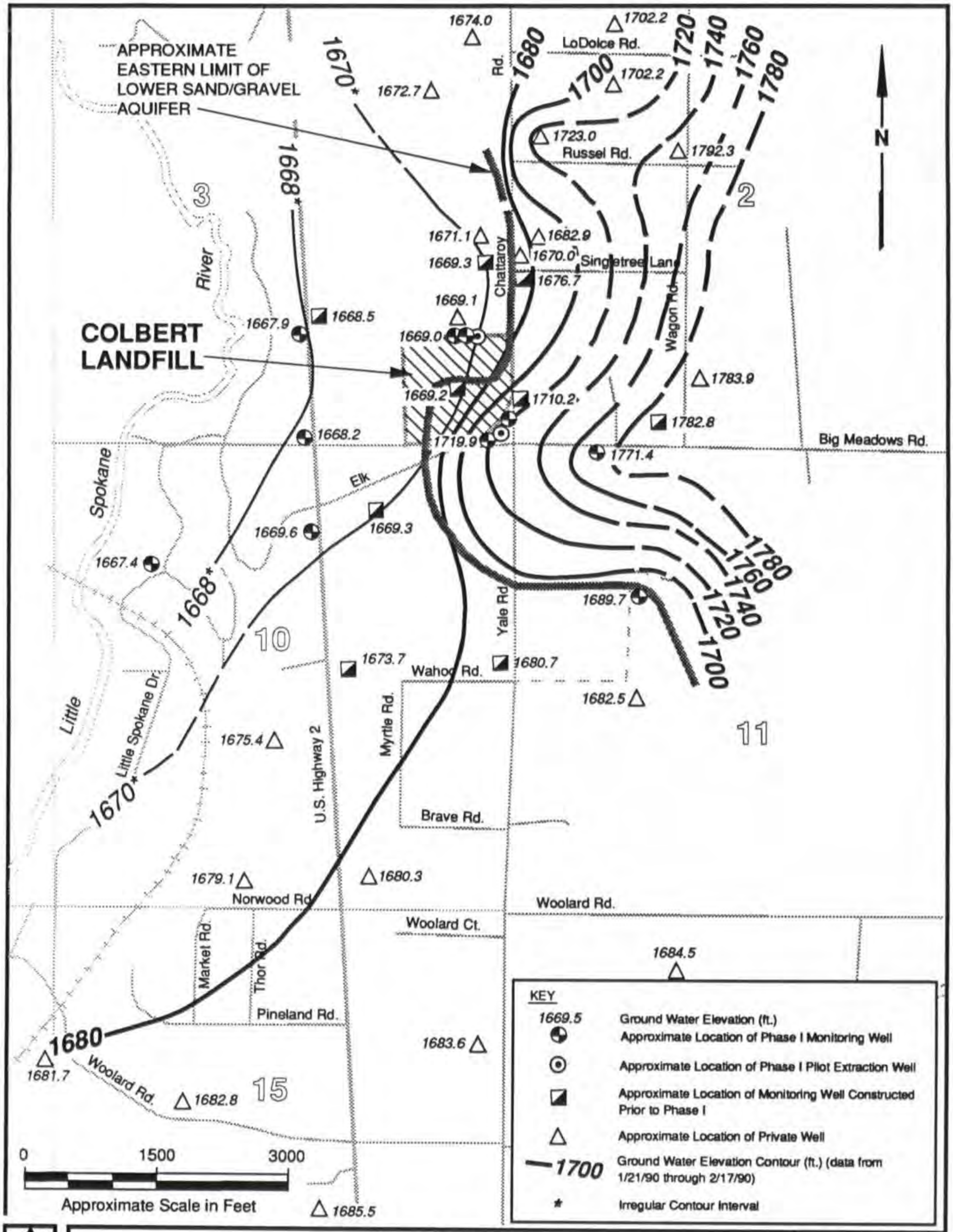
Figure B-1



Upper Aquifer
Groundwater Elevation Contours

Figure B-2

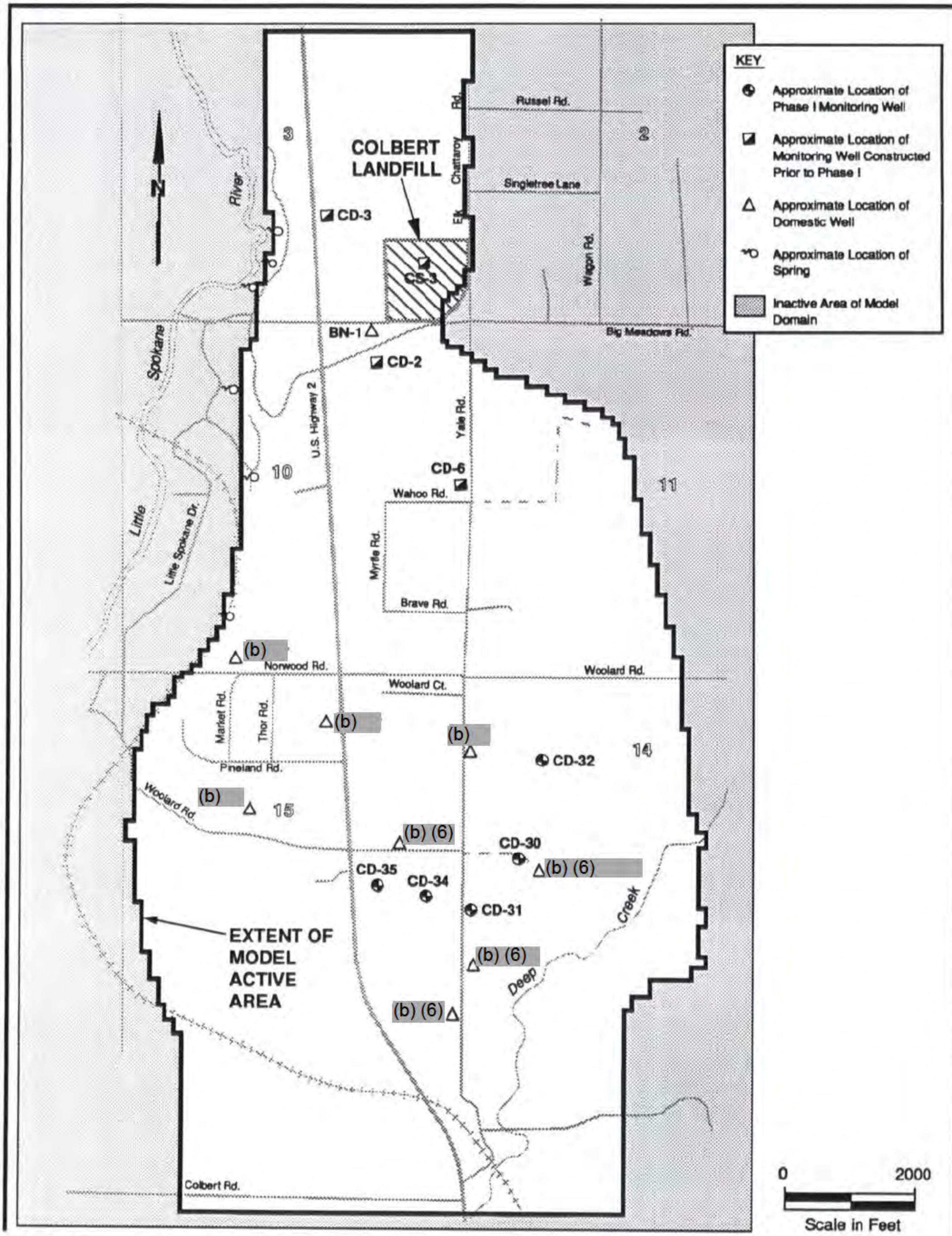
124001.72 Spokane Co./Colbert Landfill/ RD/RA Phase II / Final Extraction Well Plan - Appendix B 8/92



Lower Aquifers
Groundwater Elevation Contours

Figure B-3

124001.72 Spokane Co./Colbert Landfill/ RD/RA Phase II / Final Extraction Well Plan - Appendix B 8/92



Model Domain for Upper Aquifer

Figure B-4

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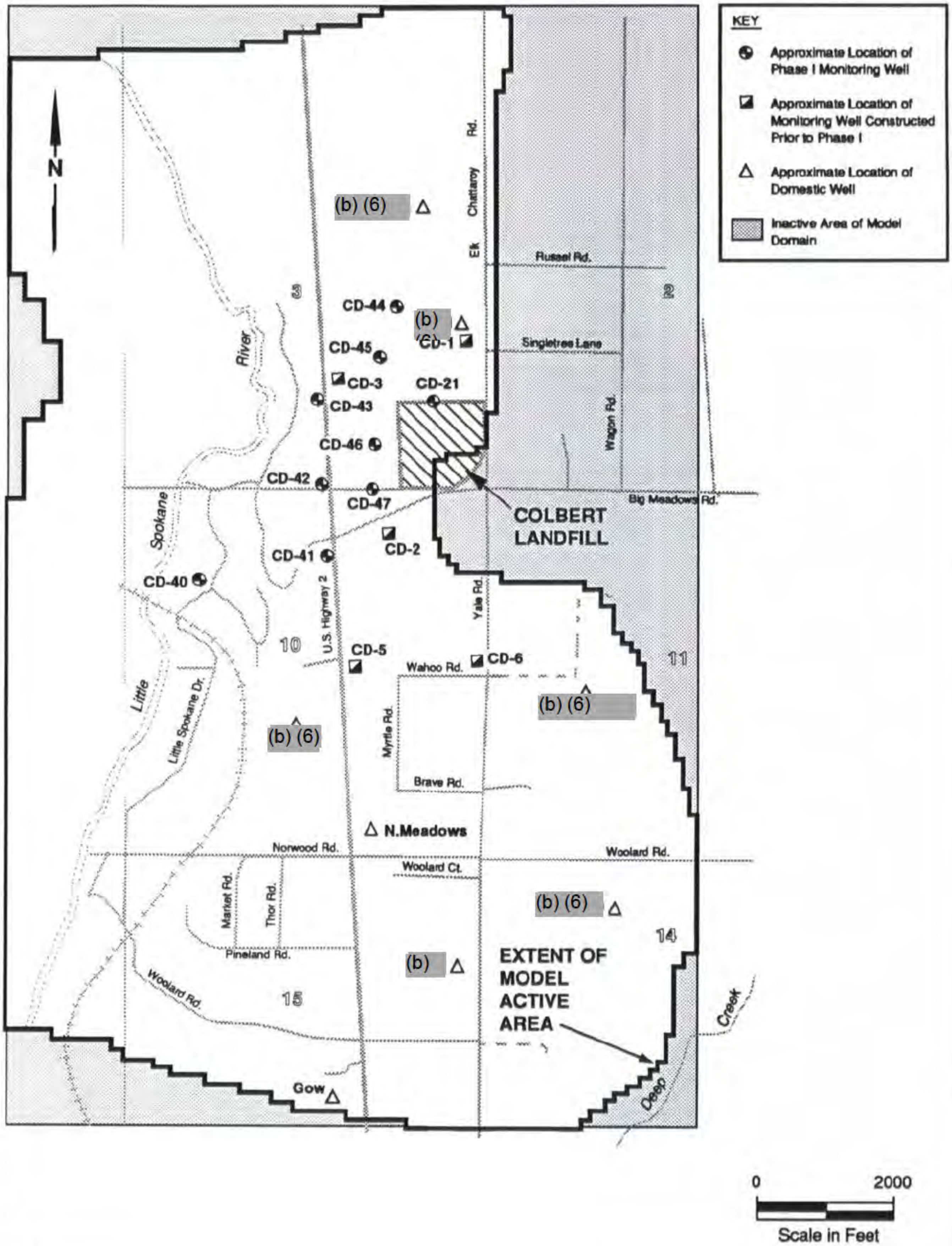
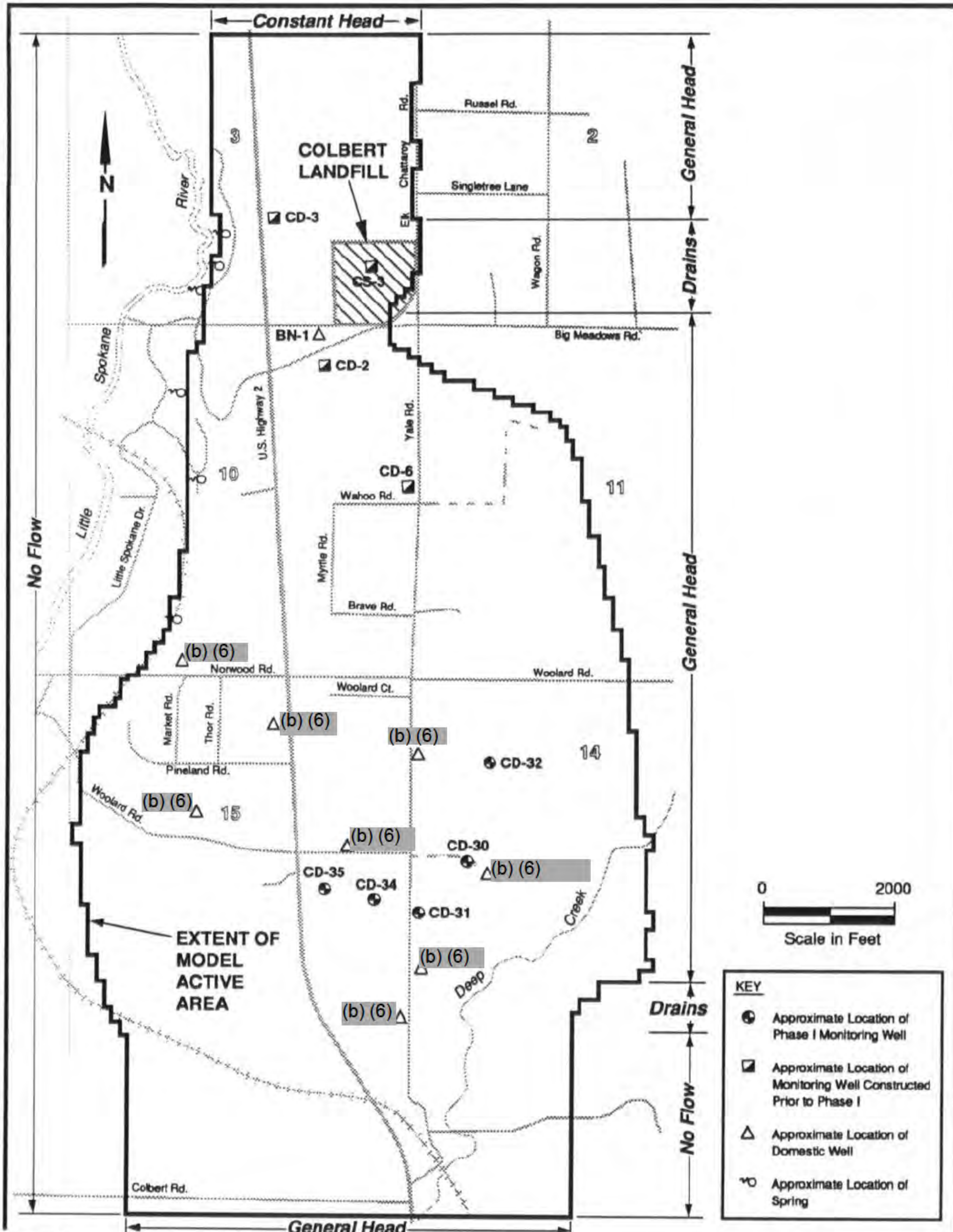


Model Domain for Lower Aquifer

Figure B-5

124001.72 Spokane Co/Colbert Landfill/ RD/RA Phase II / Final Extraction Well Plan - Appendix B 8/92



Upper Aquifer
Model Boundary Conditions

Figure B-6

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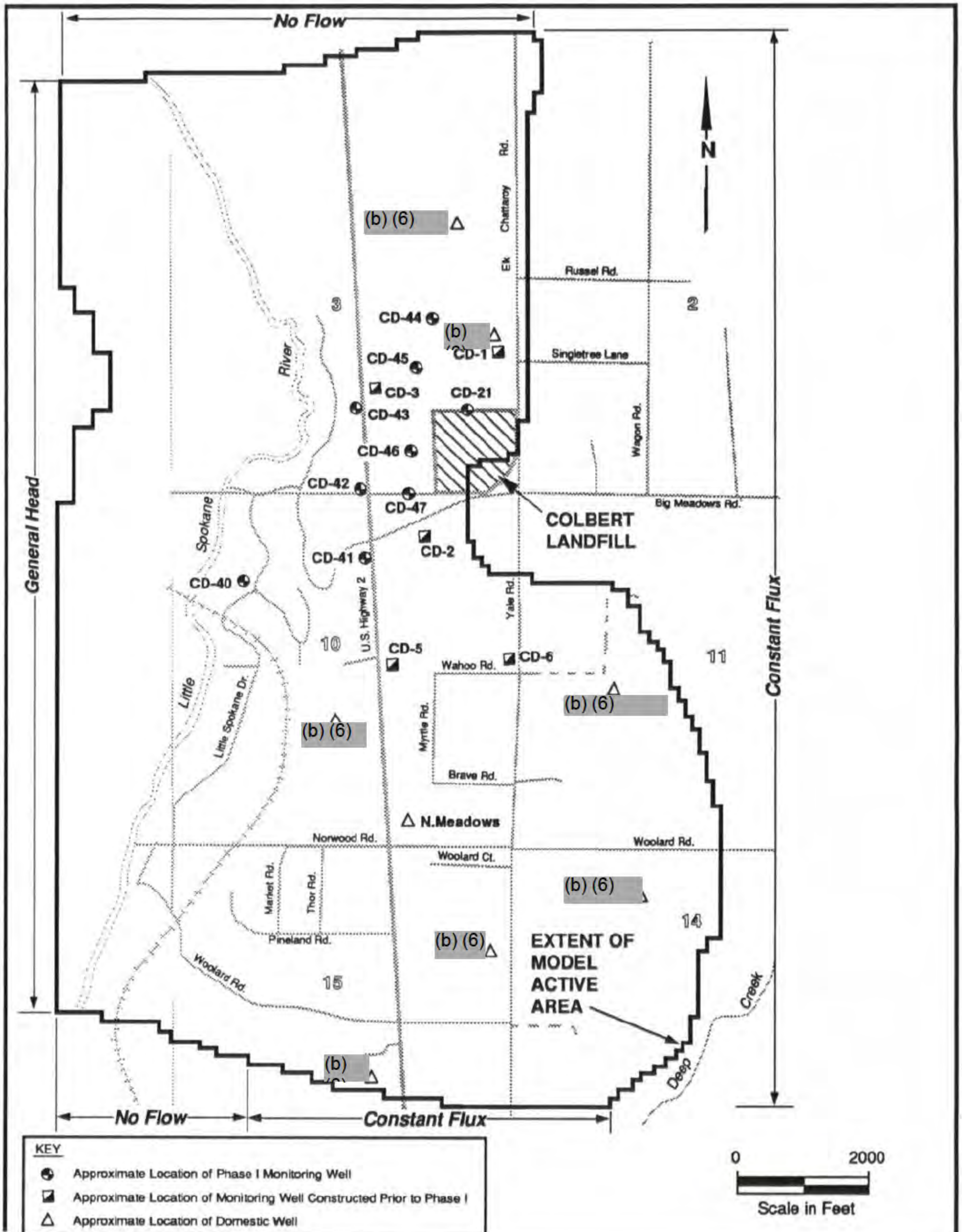

Lower Aquifer
Model Boundary Conditions

Figure B-7

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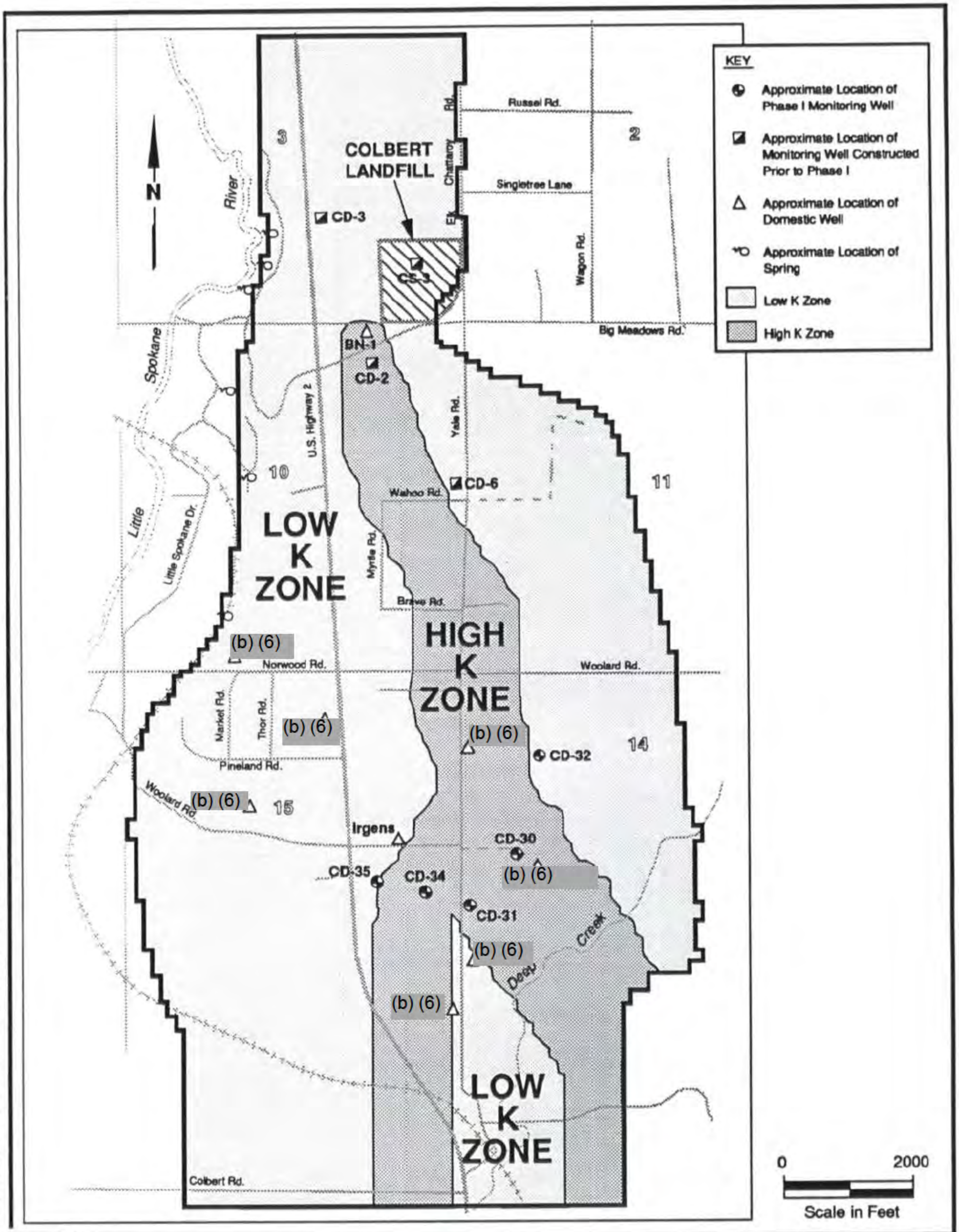

Hydraulic Conductivity Distribution for Upper Aquifer

Figure B-8

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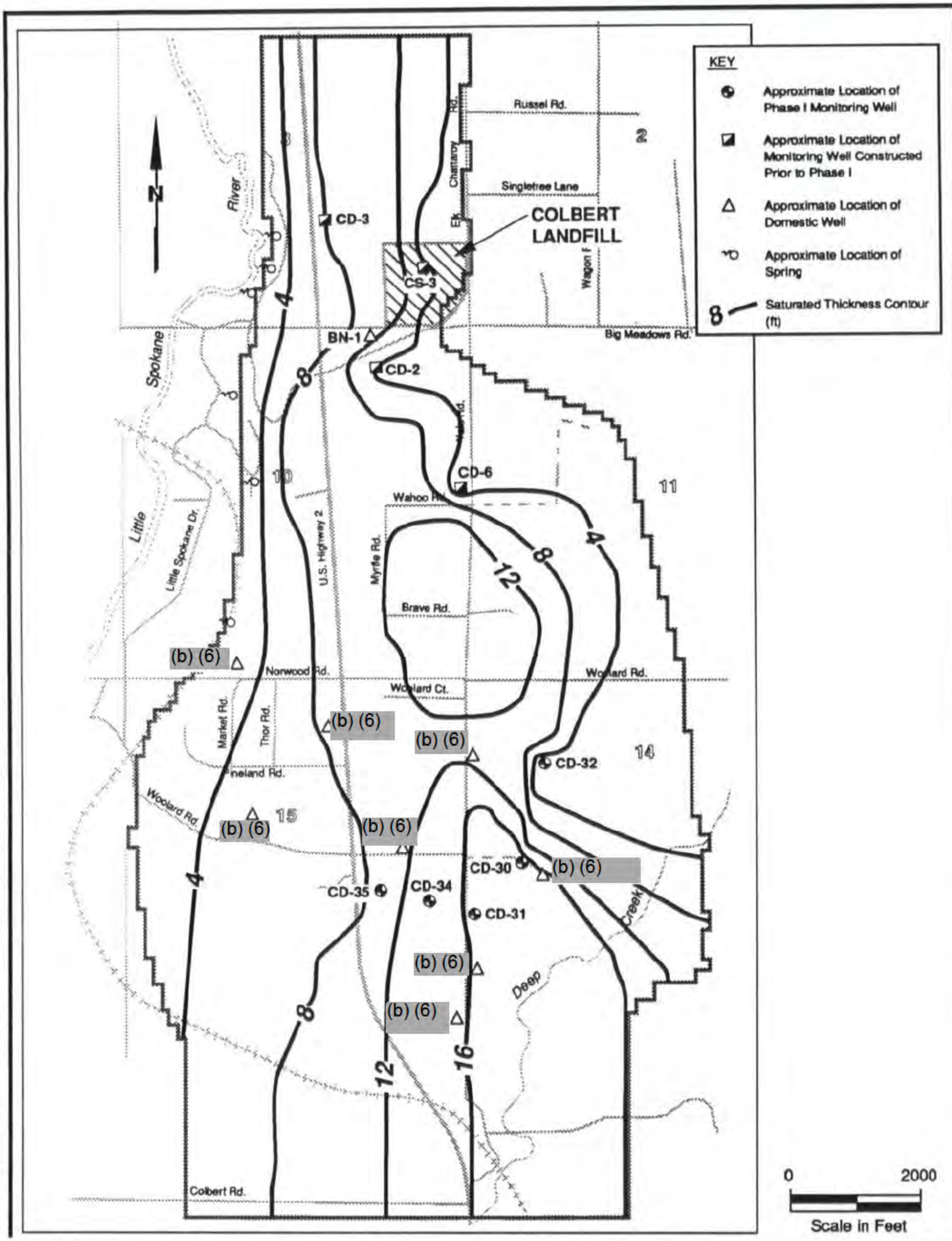

Saturated Thickness Used for Upper Aquifer Model

Figure B-9

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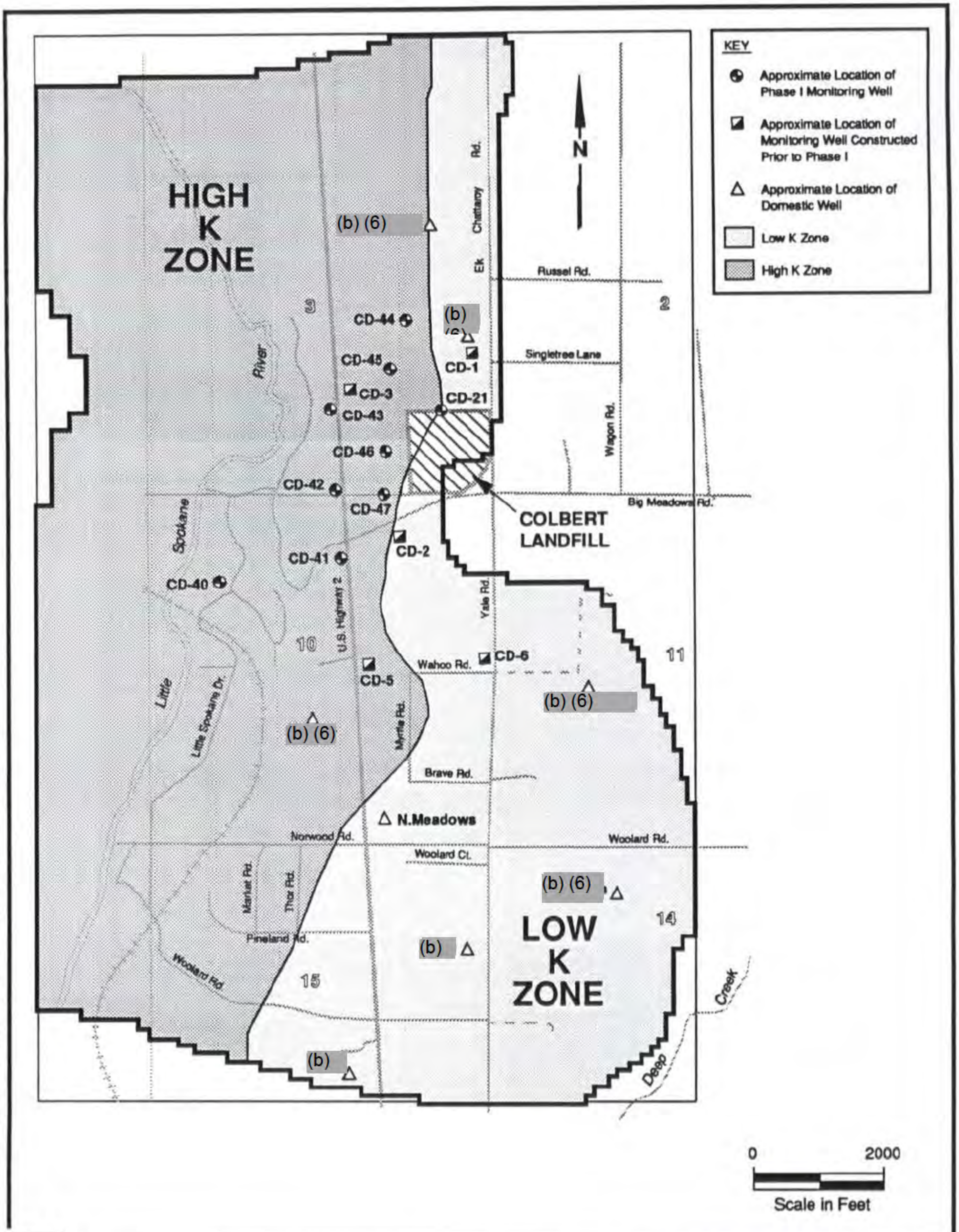
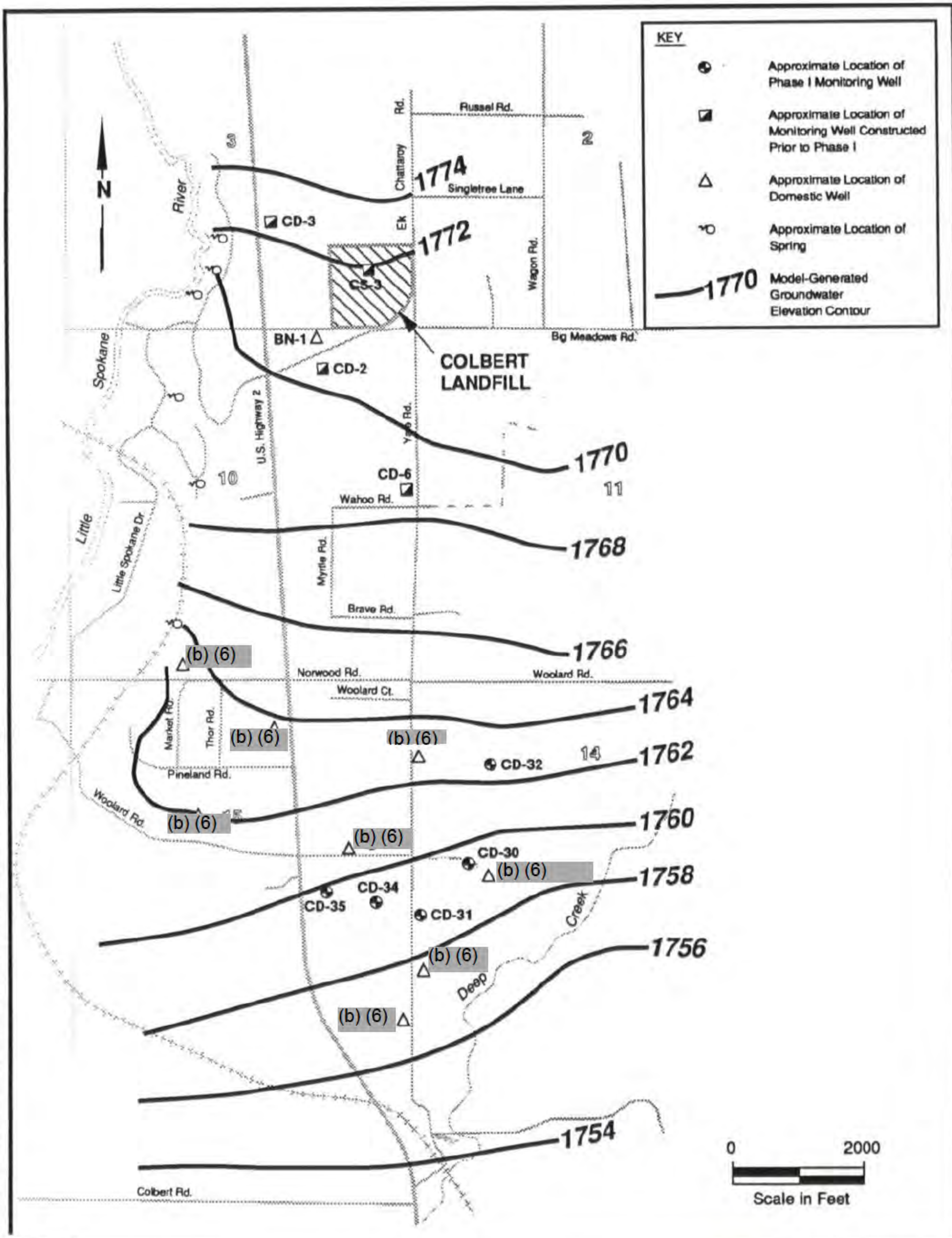


Hydraulic Conductivity Distribution for Lower Aquifer

Figure B-10



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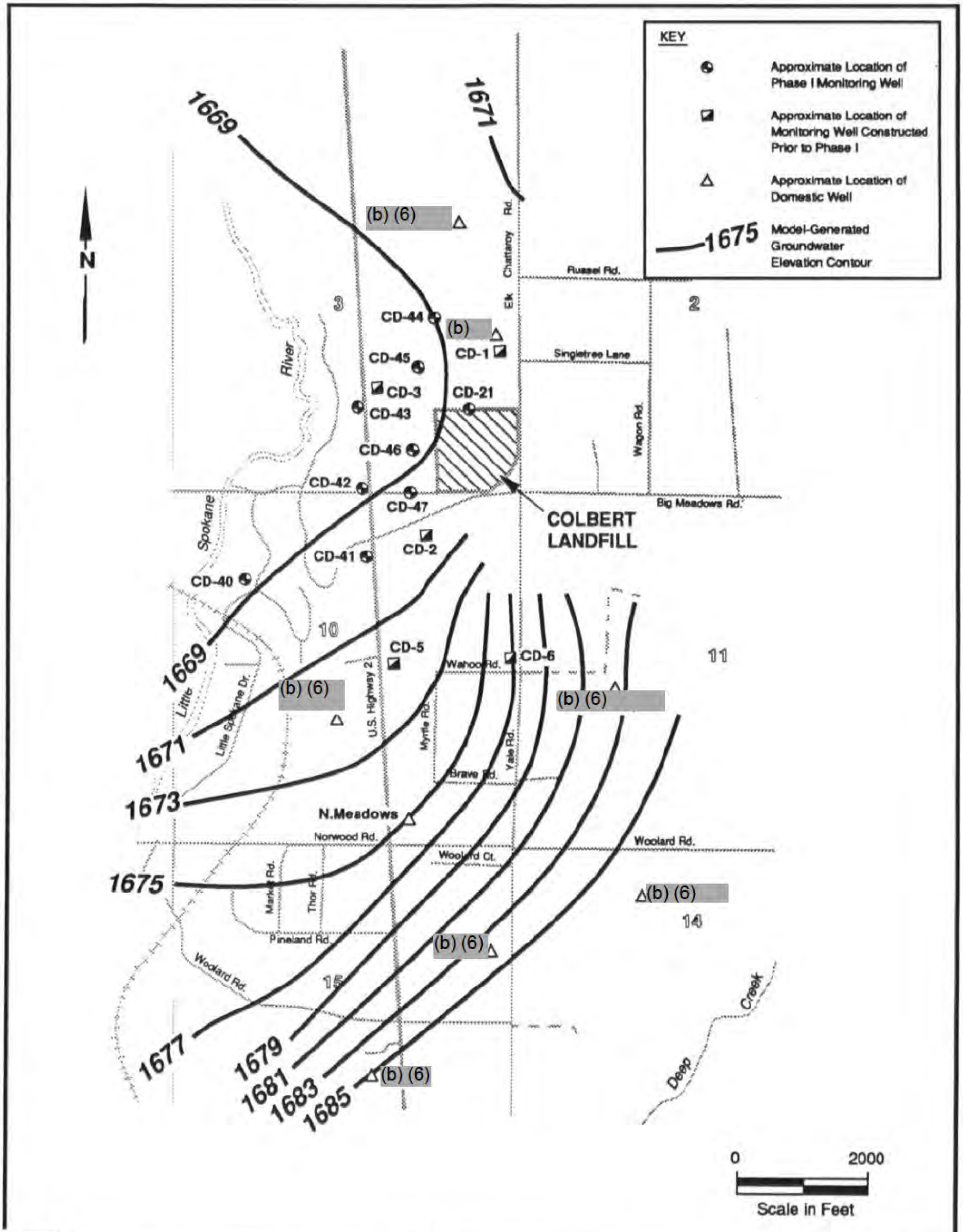
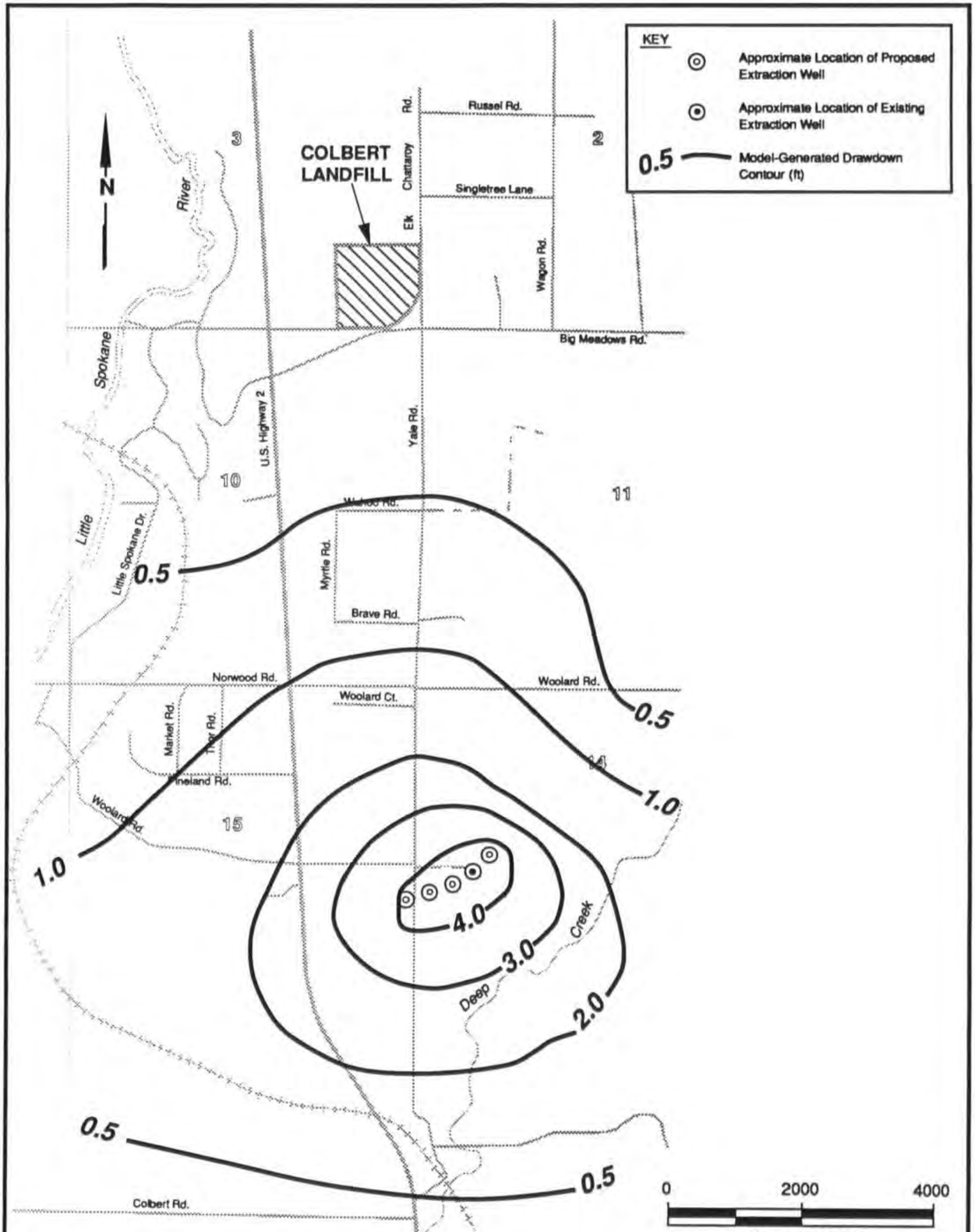
Upper Aquifer
Model-Generated Groundwater Elevation Contours (Nonpumping)

Figure B-11



Lower Aquifer
Model-Generated Groundwater Elevation Contours (Nonpumping)

Figure B-12



Upper Aquifer
Anticipated Regional Drawdown

Figure B-13

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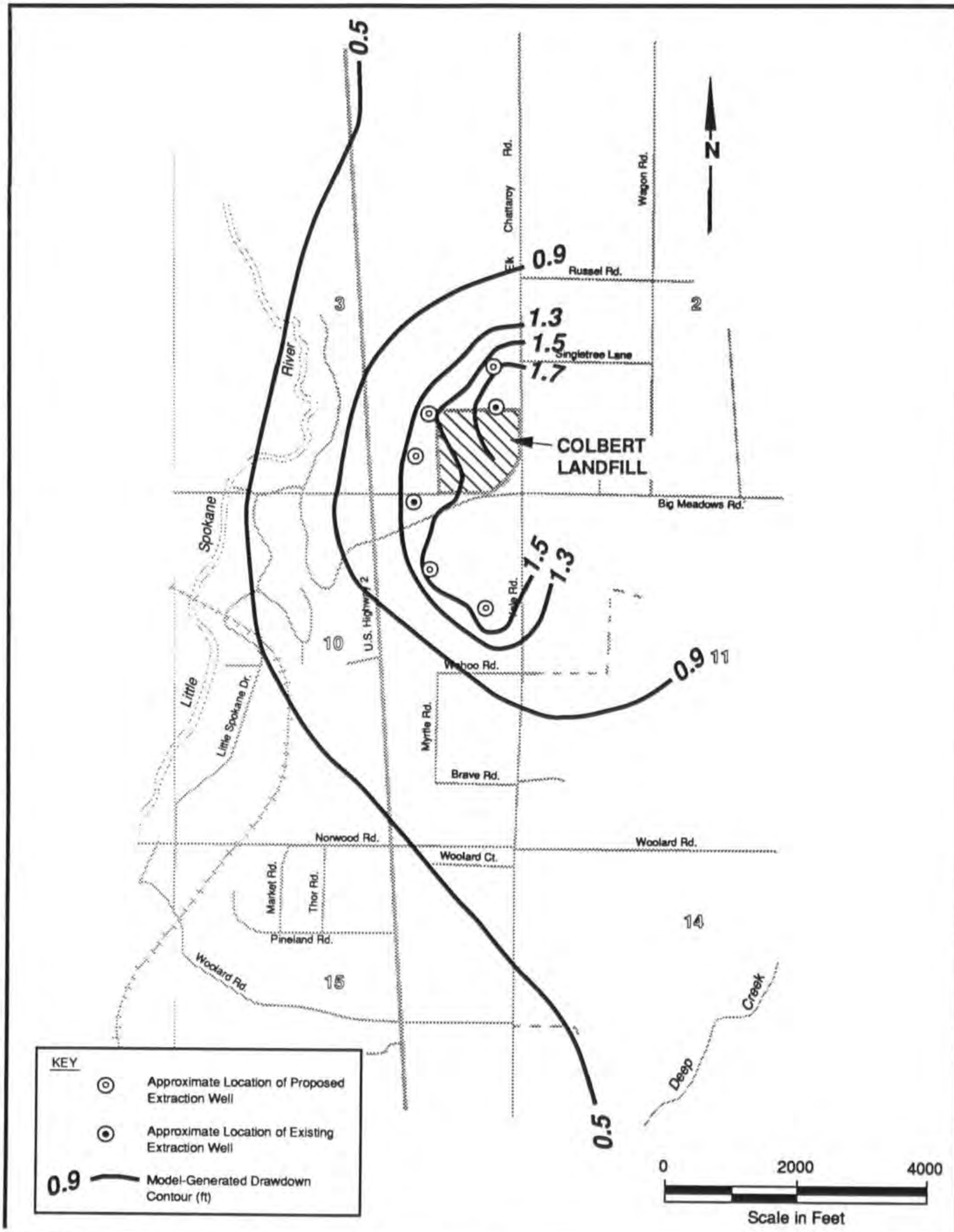

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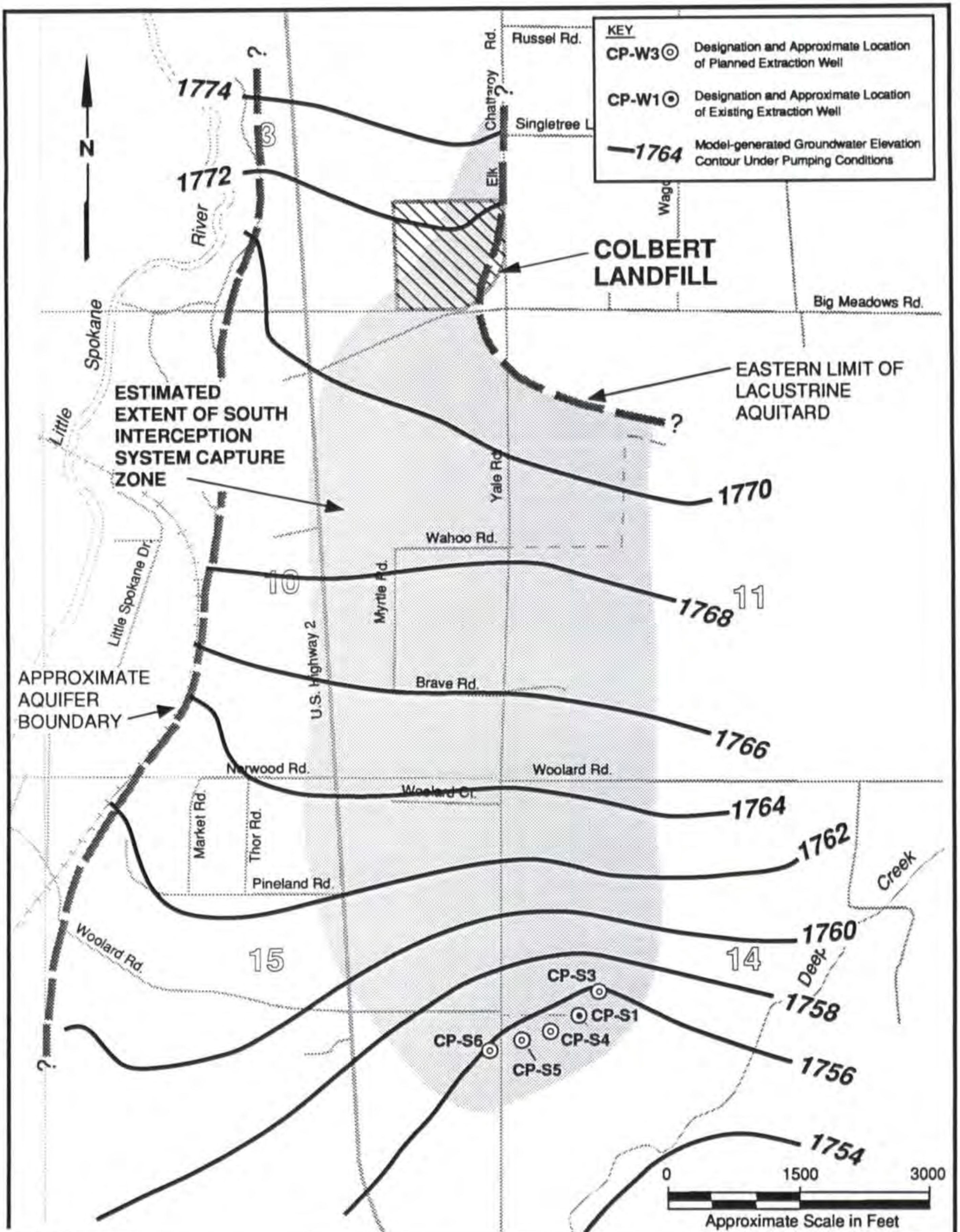
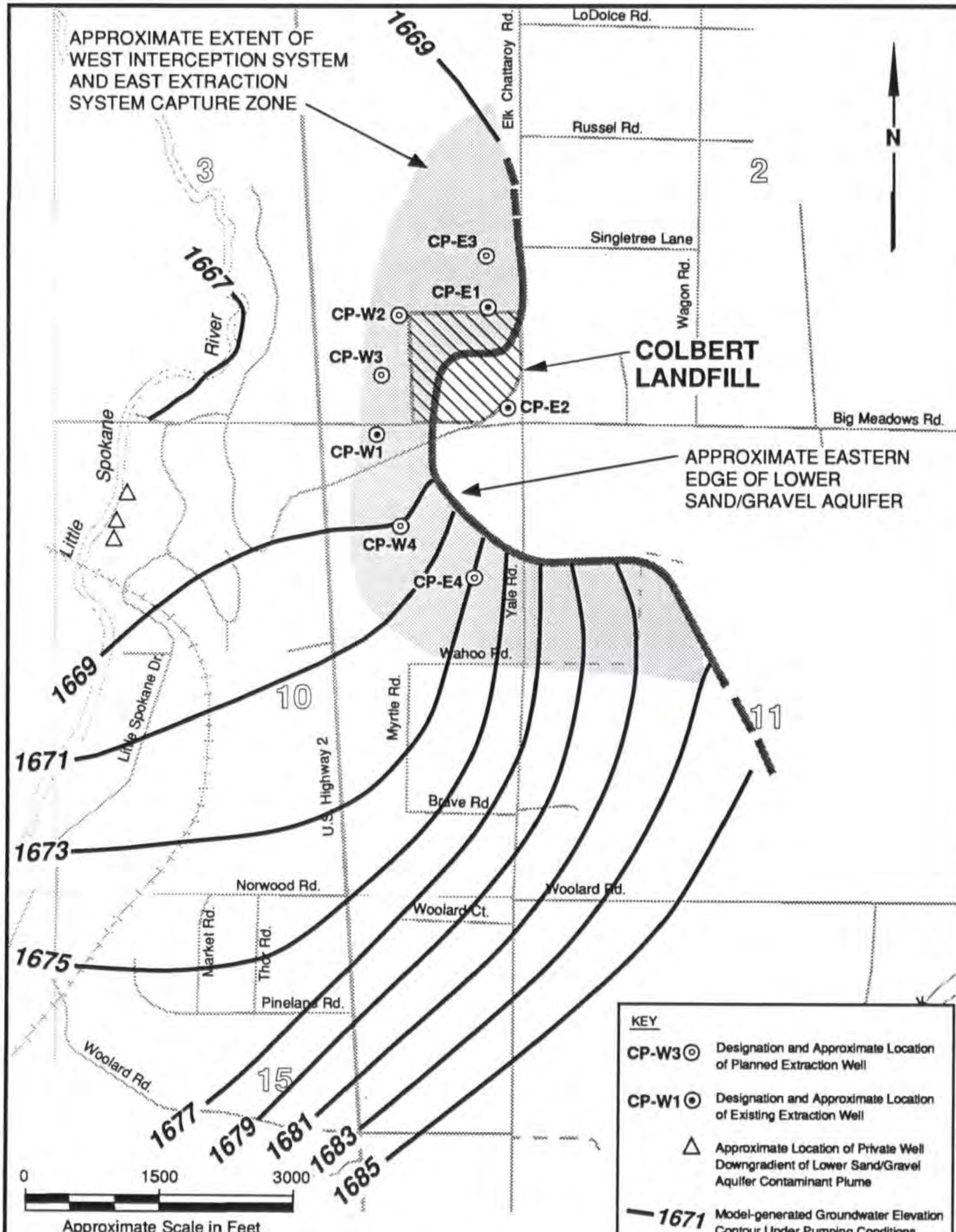
Lower Aquifer
Anticipated Regional Drawdown

Figure B-14



Upper Aquifer Capture Zone

Figure B-15



Lower Aquifer Capture Zone	Figure B-16

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TABLE B-1

HYDRAULIC CONDUCTIVITY RANGE
FOR UPPER AND LOWER BOUND FLOW SCENARIOS

	Hydraulic Conductivity Range (ft/day)	
Model	Upper Bound Flow Scenario	Lower Bound Flow Scenario
Upper Aquifer	500-640	410-530
Lower Aquifer	200-270	110-180

TABLE B-2

UPPER AQUIFER RESIDUAL HEAD VALUES

Well	Measured Head (ft MSL)	Lower Bound Flow Scenario		Upper Bound Flow Scenario	
		Model-Predicted Head (ft MSL)	Residual Head (ft)	Model-Predicted Head (ft MSL)	Residual Head (ft)
CD-2	1770.4	1770.7	-0.3	1770.4	0
CD-3	1773.1	1772.7	0.4	1772.5	0.6
CS-3	1773.5	1771.7	1.8	1771.6	1.9
CD-6	1772.2	1769.0	3.2	1768.4	3.8
CD-30	1758.0	1759.7	-1.7	1759.3	-1.3
CD-31	1759.0	1759.2	-0.2	1758.8	0.2
CD-32	1759.5	1763.2	-3.7	1762.7	-3.2
CD-34	1759.9	1759.6	0.3	1759.2	0.7
CD-35	1760.0	1760.0	0	1759.5	0.5
BN-1	1771.0	1771.0	0	1770.7	0.3
(b) (6) [redacted]	1757.2	1756.9	0.3	1756.7	0.5
	1760.1	1761.0	-0.9	1760.5	-0.4
	1762.8	1763.3	-0.5	1763.0	-0.2
	1762.6	1762.5	0.1	1762.0	0.6
	1760.5	1763.3	-2.8	1762.7	-2.2
	1761.4	1764.2	-2.8	1763.7	-2.3
	1758.5	1757.8	0.7	1757.5	1.0
Average Residual Head			-0.4		0.03

TABLE B-3

LOWER AQUIFER RESIDUAL HEAD VALUES

Well	Measured Head (ft MSL)	Lower Bound Flow Scenario		Upper Bound Flow Scenario	
		Model-Predicted Head (ft MSL)	Residual Head (ft)	Model-Predicted Head (ft MSL)	Residual Head (ft)
CD-1	1669.3	1669.9	-0.6	1669.8	-0.5
CD-2	1669.3	1669.2	0.1	1670.0	-0.7
CD-4	1668.5	1668.4	0.1	1668.5	0.0
CD-5	1673.7	1760.1	3.6	1672.1	1.6
CD-6	1680.7	1676.0	4.7	1676.9	3.8
CD-21	1669.0	1669.3	-0.3	1669.5	-0.5
CD-40	1667.4	1668.3	-0.9	1668.6	-1.2
CD-41	1669.6	1668.8	0.8	1669.7	-0.1
CD-42	1668.2	1668.4	-0.2	1668.9	-0.7
CD-43	1667.9	1668.2	-0.3	1668.3	-0.4
CD-44	1669.5	1668.8	0.7	1669.1	0.4
CD-45	1668.9	1668.6	0.3	1668.8	0.1
CD-46	1668.4	1668.5	-0.1	1668.9	-0.5
CD-47	1668.5	1668.6	-0.1	1669.1	-0.6
(b) (6) [redacted]	1682.5	1683.3	-0.8	1682.7	-0.2
	1685.5	1680.2	5.3	1684.7	0.8
	1672.7	1669.4	3.3	1669.7	3.0
	1683.6	1681.8	1.8	1684.7	-1.1
	1684.5	1686.6	-2.1	1687.6	-3.1
	1671.1	1669.7	1.4	1669.7	1.4
	1675.4	1670.1	5.3	1672.3	3.1
Average Residual Head			1.0		0.2

TABLE B-4

GROUNDWATER FLUX ESTIMATES

Upper Aquifer

Flux Across Southern Boundary

1. Estimated groundwater flux across southwest-northeast trending line through Irgens Well (from Phase I data):

Average Gradient (i)	=	0.0017
Average K	=	550 ft/day
Area (A)	=	11,000 ft (length) x 6 ft (average saturated thickness)
Estimated Flux (Q)=KiA	=	61700 ft^3/day

2. Model-predicted flux across south model boundary (upper bound scenario):

Average discharge = 110,300 ft^3/day

Downgradient area between line used for estimate in (1) and model boundary
= 5,000 ft x 6,600 ft
= 33,000,000 ft^3/day

Precipitation recharging downgradient area (@6 inches/year)
= 45,200 ft^3/day

Equivalent model discharge
= 110,300 - 45,200 = 65,100 ft^3/day

Lower Aquifer

Groundwater Flux to River

1. Estimate from Ecology Study (1975):

Average discharge @ Darftord = 65 ft^3/s from groundwater

Assume groundwater discharge is distributed evenly over Chatteroy-Dartford river reach (9.5 miles); river reach in model is 2.5 miles
= 2.5 miles /9.5 miles = 26.3 percent

65 cfs x 26.3% = 17 cfs = 1,470,000 ft^3/day

Assume one-half flow from east side of river = 734,000 ft^3/day

2. Estimated flux across north-south trending line through CP-W1 (from Phase I data):

Average gradient (i)	=	0.001
Average K	=	200 ft/day (average saturated thickness)
Area (A)	=	2.5 miles (length) x 180 ft
Q=KiA	=	475,000 ft^3/day

3. Model-predicted flux to river

Average discharge (upper bound scenario) = 400,000 ft^3/day

TABLE B-5

MODEL-PREDICTED PUMPING RATES REQUIRED FOR CONTAMINANT CAPTURE

Model	Well Designation	Lower Bound Flow Pumping Rate (gpm)	Upper Bound Flow Pumping Rate (gpm)	
			Modeled	Gradient Adjusted[a]
Upper Aquifer	CP-S1	55	60	N/A
	CP-S3	50	50	N/A
	CP-S4	50	50	N/A
	CP-S5	50	60	N/A
	CP-S6	50	60	N/A
Total		250	280	N/A
Lower Aquifer	CP-E1	60	60	80
	CP-E2[b]	5	5	5
	CP-E3	50	50	65
	CP-E4	50	50	65
	CP-W1	60	100	130
	CP-W2	70	100	130
	CP-W3	70	100	130
	CP-W4	70	100	130
Total		435	565	735

(a) Modeled upper bound flow for Lower Aquifer adjusted upward by 30 percent to account for 30 percent flatter gradient in model than estimated based on Phase I data.

(b) Not in model domain, estimate from Phase I CP-E2 pumping test.

TABLE B-6

EXTRACTION WELL DRAWDOWN SUMMARY

Flow Model	Well Designation	Lower Bound Flow Scenario			Upper Bound Flow Scenario		
		s(cell)[a]	$s(well_1)$[b]	$s(well_2)$[c]	s(cell)[a]	$s(well_1)$[b]	$s(well_2)$[c]
Upper Aquifer	CP-S1	5.3	5.8	8.7	5.3	5.7	8.6
	CP-S3	5.2	5.7	8.6	5.1	5.5	8.3
	CP-S4	5.2	5.7	8.6	5.0	5.4	8.1
	CP-S5	4.7	5.5	8.3	4.7	5.5	8.3
	CP-S6	5.6	6.0	9.0	5.7	6.1	9.2
Lower Aquifer	CP-W1	1.1	1.5	6.2	1.6	1.9	7.7
	CP-W2	1.0	1.2	4.9	1.6	1.9	7.7
	CP-W3	1.0	1.2	4.9	1.6	1.9	7.7
	CP-W4	1.7	2.6	10.6	2.1	3.0	12.2
	CP-E1	1.9	2.6	5.9	2.1	2.6	5.9
	CP-E3	1.9	2.8	6.4	2.1	2.8	6.4
	CP-E4	2.3	3.6	8.2	2.2	3.2	7.3

(a) Drawdown within model cell.

(b) $s(well_1)$ = estimated well drawdown from cell drawdown using the following equation (Beljin 1987):

$$s(well_1) = s(cell) + (Q/2\pi T) \ln(re/rw)$$

Where:

re = effective well radius = 0.208 Δx (from Beljin 1987)

Δx = cell width (ft)

rw = well radius = 0.5 ft

(c) $s(well_2)$ = estimated drawdown, including well efficiency and partial penetration; well efficiency assumed to be 64 percent for Upper Aquifer wells and 78 percent for Lower Aquifer wells, and accounting for partial penetration effects in Lower Aquifer wells (Butler 1957 method).

APPENDIX C

Solute Transport Model Description

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDIX C
SOLUTE TRANSPORT MODEL SIMULATIONS
FOR PHASE II GROUNDWATER EXTRACTION

INTRODUCTION

The purpose of this Appendix is to describe the modeling procedures used to estimate the peak influent concentrations of methylene chloride (MC) and trichloroethane (TCA) for the Phase II interception and extraction systems. These peak influent concentrations are used for design of the Phase II treatment system (Landau Associates 1992).

METHODOLOGY

The MT3D numerical solute transport code (S.S. Papadopulos & Associates 1991) was used to estimate the peak concentrations of TCA and MC by generating constituent concentration breakthrough curves for each Phase II extraction well. The modeling procedure was as follows:

1. Develop and calibrate the steady-state non-pumping groundwater flow model(s) of the aquifer system(s) using MODFLOW, and simulate Phase II pumping conditions using the calibrated models (described in Appendix B of this Preliminary Plan).
2. Output the groundwater flow model results (hydraulic heads and flow terms) to a computer file for use as input in the MT3D solute transport code.
3. Generate continuous fields of MC and TCA distribution in the Upper and Lower Sand/Gravel Aquifers for input to MT3D as initial concentrations.
4. Simulate a continuous source for MC and TCA, based on measured concentrations (at the Landfill).
5. Format the groundwater flow and constituent concentration MT3D files for input to the MT3D solute transport model.
6. Execute the MT3D solute transport code for MC and TCA.
7. Generate breakthrough curves for TCA and MC at each extraction well . Output from MT3D consists of constituent concentrations as a function of time (breakthrough curves) at predetermined observation points (extraction wells).
8. Combine the concentration versus time data for each extraction well (using constituent concentrations and extraction well flow rates to determine relative contribution) to estimate the constituent concentrations for 1) common pipelines (combinations of wells plumbed together), and 2) the combined Phase II system.

COMPUTER PROGRAM

The MT3D computer program was used to simulate contaminant migration under pumping conditions and to estimate the concentration breakthrough curves at the proposed extraction wells. MT3D simulates the advection, dispersion and chemical reaction of a constituent in groundwater in a two- or three-dimensional flow field, with various boundary conditions and external sources or sinks. The solute transport code can simulate the change in concentration of a miscible single-species in groundwater as a function of time and location.

MT3D can be used in conjunction with any block-centered finite-difference groundwater flow model. The groundwater flow model is developed and calibrated independently of MT3D. Output from the flow model (hydraulic heads and flow terms) are used as input to MT3D.

Longitudinal and transverse dispersion were not accounted for in this study. These processes were omitted to provide a conservative estimate for design purposes, that is, to maximize the predicted peak concentrations.

INPUT PARAMETERS

Solute transport simulations for both the Upper and Lower Sand/Gravel Aquifer models required the input of the hydraulic head and flow terms from the groundwater flow model (MODFLOW), the continuous concentration fields for the constituents, source terms, and solute transport parameters.

The upperbound flow simulations for Phase II groundwater extraction were used as input for solute transport modeling. The proposed location of Phase II extraction wells are shown on Figure C-1. South Interception System wells (CP-S's) extract groundwater from the Upper Sand/Gravel Aquifer. West Interception System Wells (CP-W's) and East Extraction System wells (CP-E's) extract groundwater from the Lower Sand/Gravel Aquifer. Groundwater flow model pumping rates for Phase II extraction wells are provided in Table C-1.

TCA and MC concentration distribution were developed based on groundwater quality data collected during Phase I. TCA groundwater quality data used for the Upper and Lower Sand/Gravel Aquifers are presented on Figures C-2 and C-3, respectively. MC groundwater quality data for the Lower Sand/Gravel Aquifer is presented on Figure C-4. Significant concentrations of MC were not detected in the Upper Sand/Gravel Aquifer during Phase I, so MC for the Upper Sand/Gravel Aquifer was not simulated. Continuous fields of the constituent distributions were generated from Phase I groundwater monitoring data using the data contouring package SURFER, and pMAP (a geographic information system). A retardation factor of 2.0 was used for TCA in the Upper and Lower Sand/Gravel Aquifer solute transport simulations. A retardation factor of 1.0 (simulating no retardation) was used for MC solute transport simulations.

SIMULATION RESULTS

Concentration versus time for TCA and MC from the Phase II extractions wells were provided as output from MT3D. MT3D-generated estimates of maximum (peak) concentrations of TCA for Upper Sand/Gravel Aquifer extraction wells range from 180 to 620 parts per billion (ppb). Estimated maximum concentrations of MC and TCA for Lower Sand/Gravel Aquifer extraction wells range from 0 to 3,400 ppb and 310 to 2,800 ppb, respectively. Estimated maximum concentrations for individual extraction wells are provided in Table C-1.

The estimated maximum concentrations and flow rates of MC and TCA from the Upper and Lower Aquifers were combined to determine the maximum concentrations for common pipelines and for the total flow entering the treatment system. Concentrations were combined at each time step using the following equation:

$$C_c = \frac{C_1Q_1}{Q_c} + \frac{C_2Q_2}{Q_c} + \ldots$$

Where

C_c = combined concentration (pipeline or system total)

C_1 = concentration for given extraction well

Q_1 = flow rate for given extraction well

Q_c = combined flow rate (pipeline or system total)

Time versus concentration data were then plotted for about the first 1.5 years of operation to estimate peak pipeline concentrations (pipeline designations for each well are provided in Table C-1) and total system peak concentrations, as shown on Figure C-5 and C-6 for TCA and MC, respectively. The maximum concentration of MC and TCA for each pipeline, and for the treatment system is shown in Table C-2. As shown on Figures C-5 and C-6, peak concentrations are anticipated to occur early in Phase II operation.

MODEL LIMITATIONS

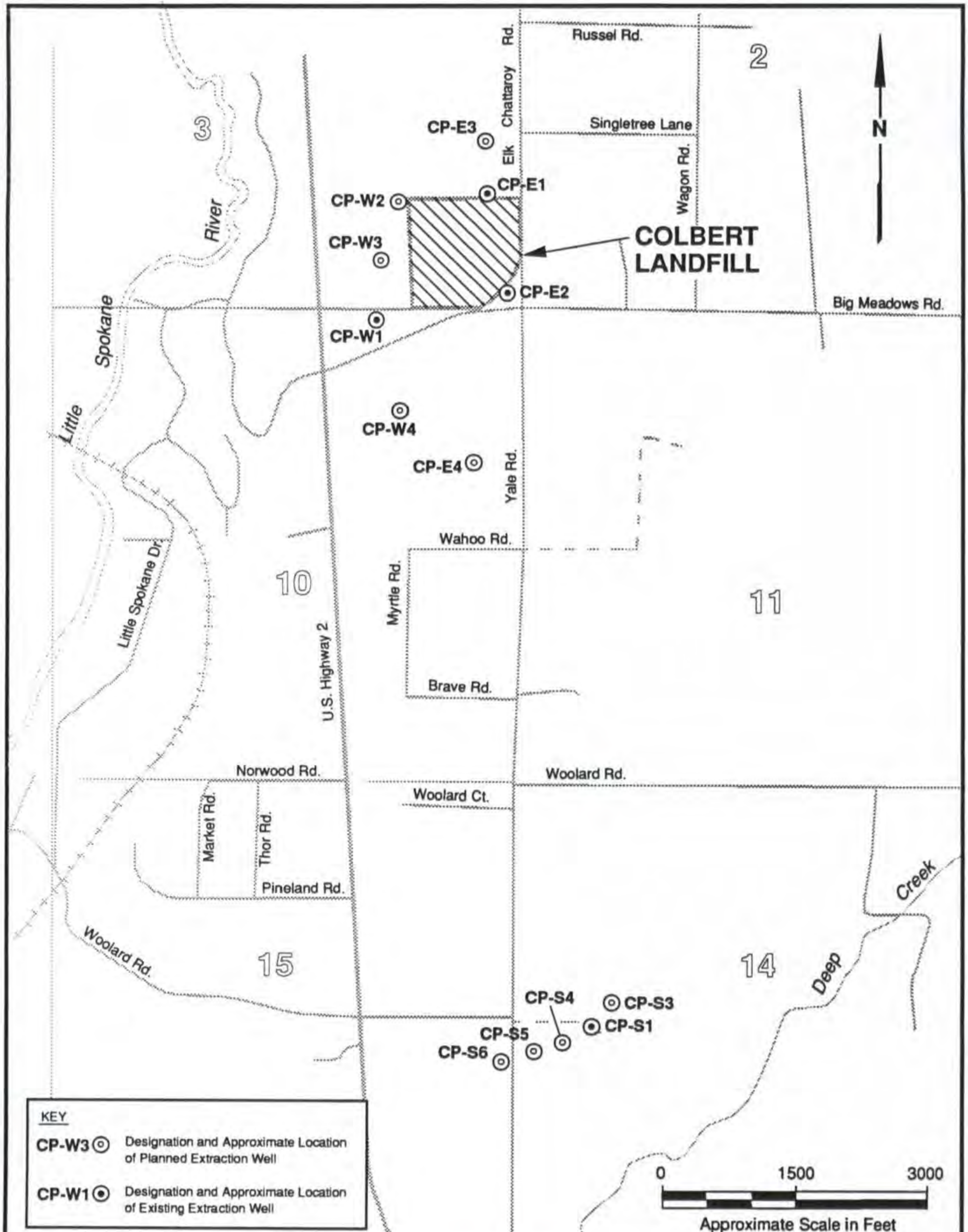
The accuracy of results for the solute transport modeling presented in this Appendix are limited by the unknowns and limitation discussed in Appendix B for the groundwater flow models. Additional assumptions made in the generation of the input parameters for MT3D further limit the accuracy of results.

The solute transport modeling was performed to develop conservative estimates of maximum constituent concentrations, which are expected to occur shortly after system startup, and the applicability of the results are limited to this purpose. In general, assumptions were made that will provide a conservative (high) estimate of maximum constituent concentrations. Although Figures C-5 and C-6 show concentration versus time for TCA and MC, the accuracy of the simulations are anticipated to decrease with time from the initial time step. Because the predicted maximum concentrations occur early in the simulations, the modeling is a useful tool in developing the data necessary for the treatment system design. Despite the limitations discussed herein, it should provide a more accurate estimate of peak influent concentration than others commonly employed for such estimates.

REFERENCES

Landau Associates, Inc. 1992. Preliminary Treatment and Discharge Plan. Phase II Remedial Design/Remedial Action. Colbert Landfill. March 1992.

S.S. Papadopulos and Associates. 1991. MT3D—A Modular Three-Dimensional Transport Model for Simulation of Advection, Dispersion, and Chemical Reaction of Contaminants in Groundwater Systems, Version 1.06, Reference Manual, Rockville, MD.



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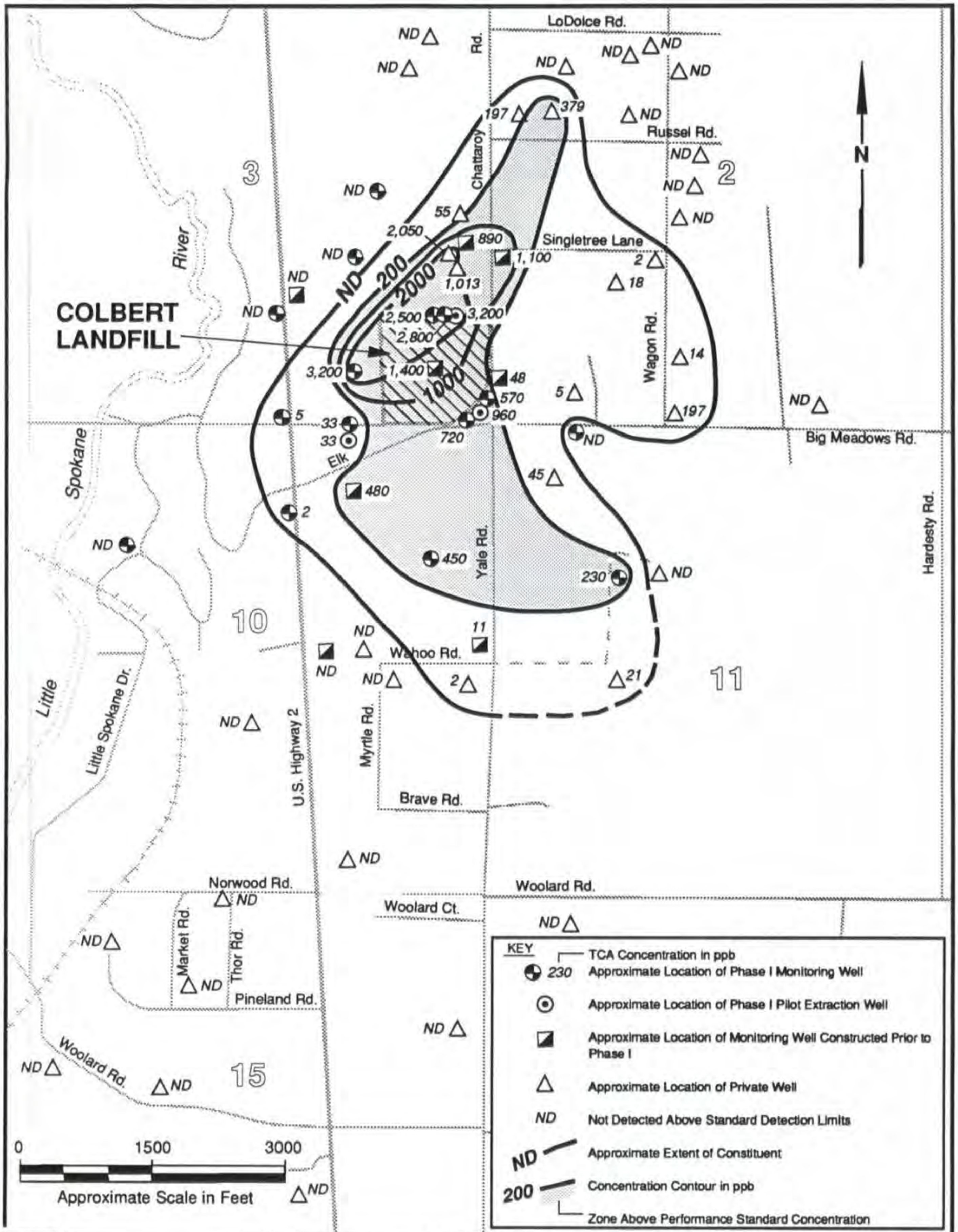
Location of Phase II Extraction Wells

Figure C-1



Lower Aquifers
TCA Distribution

Figure C-2

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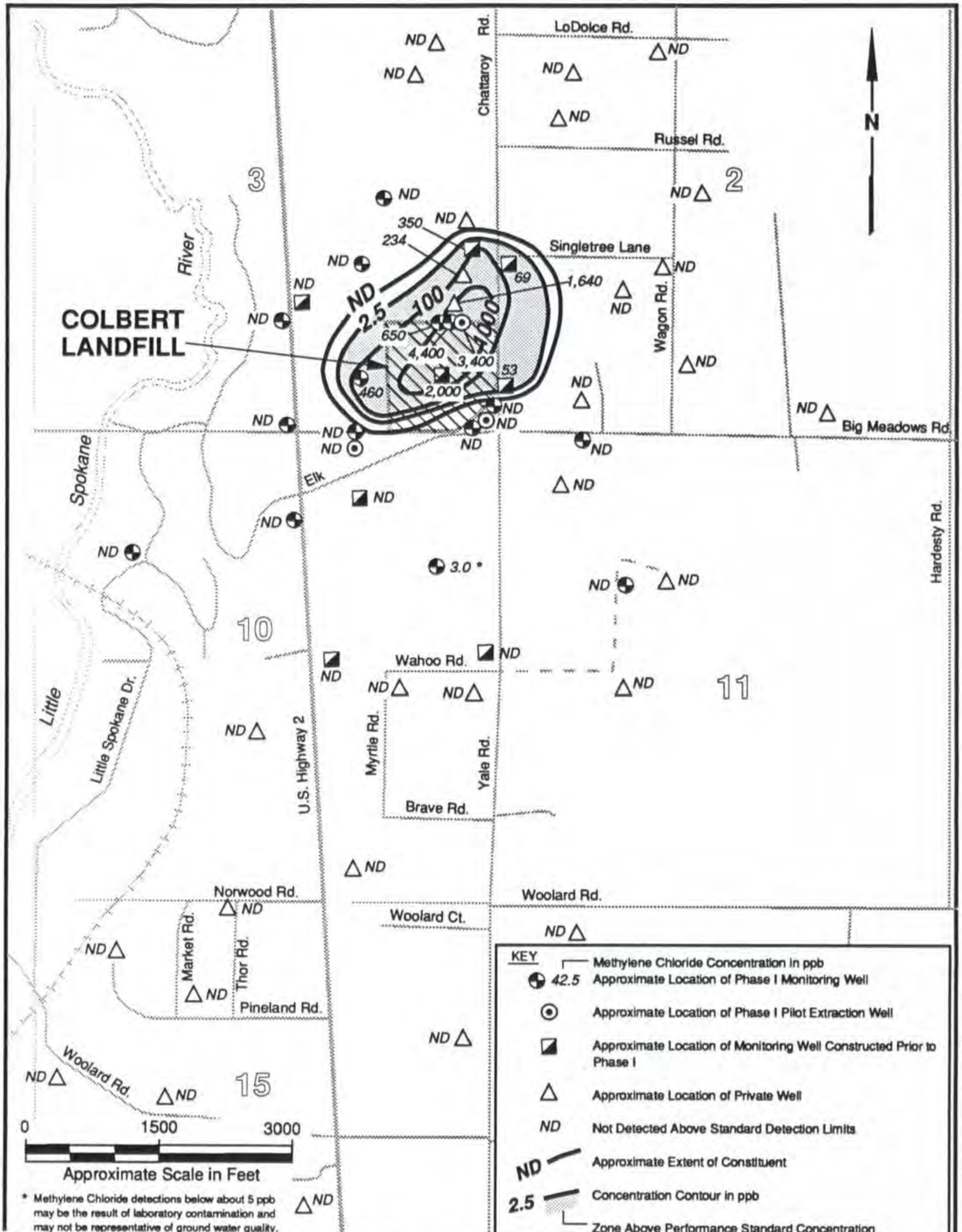

Lower Aquifers
Methylene Chloride Distribution

Figure C-3

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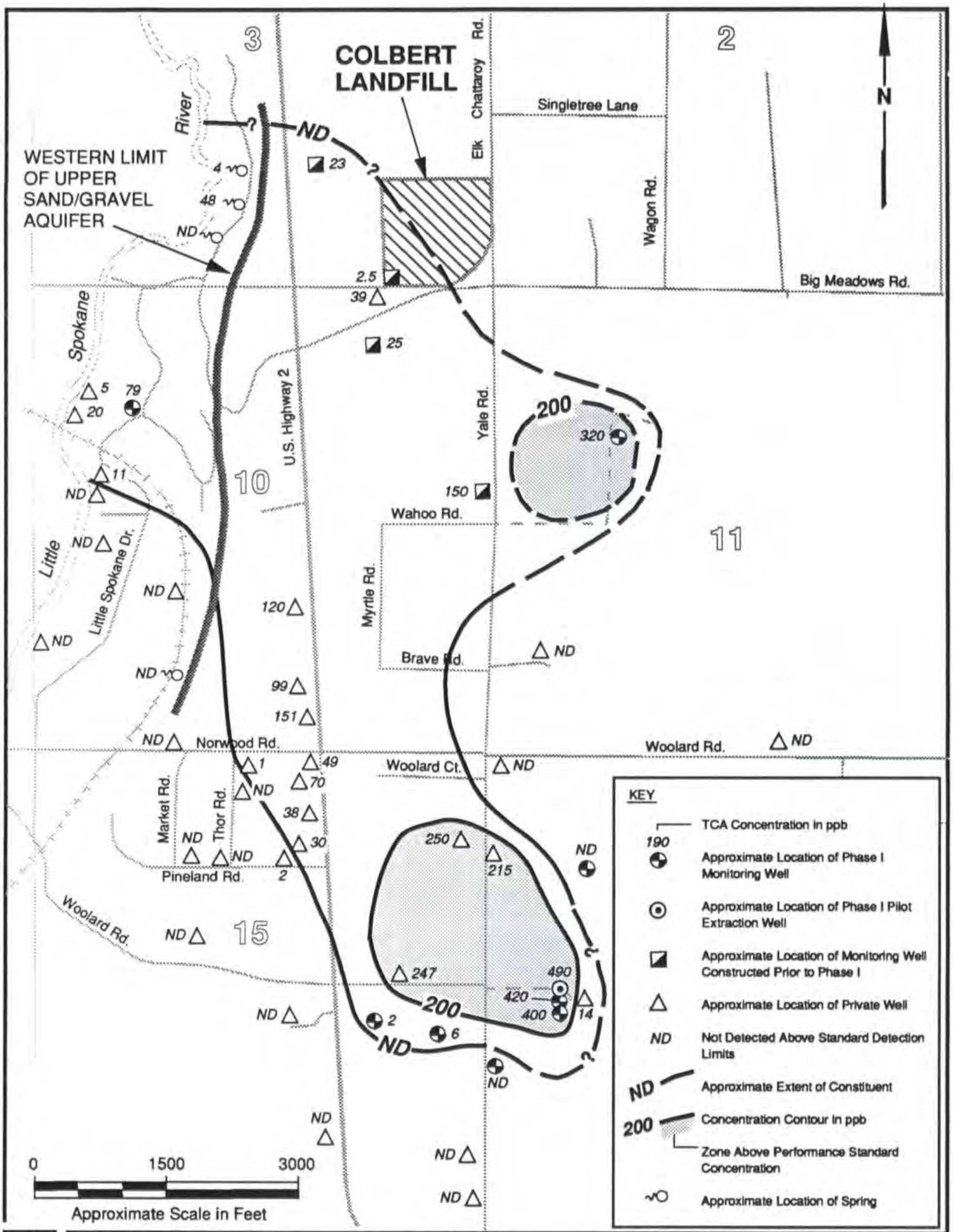
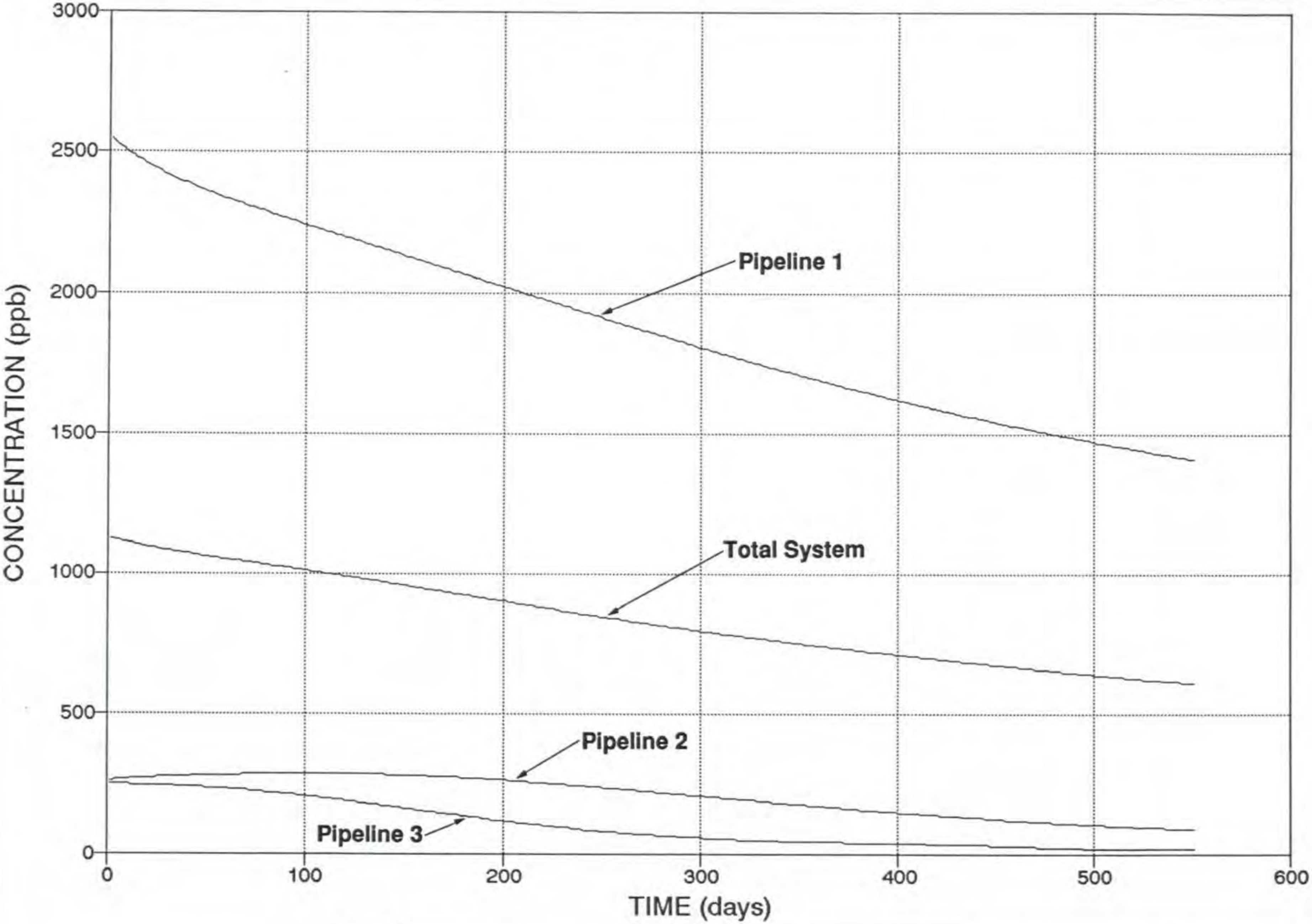


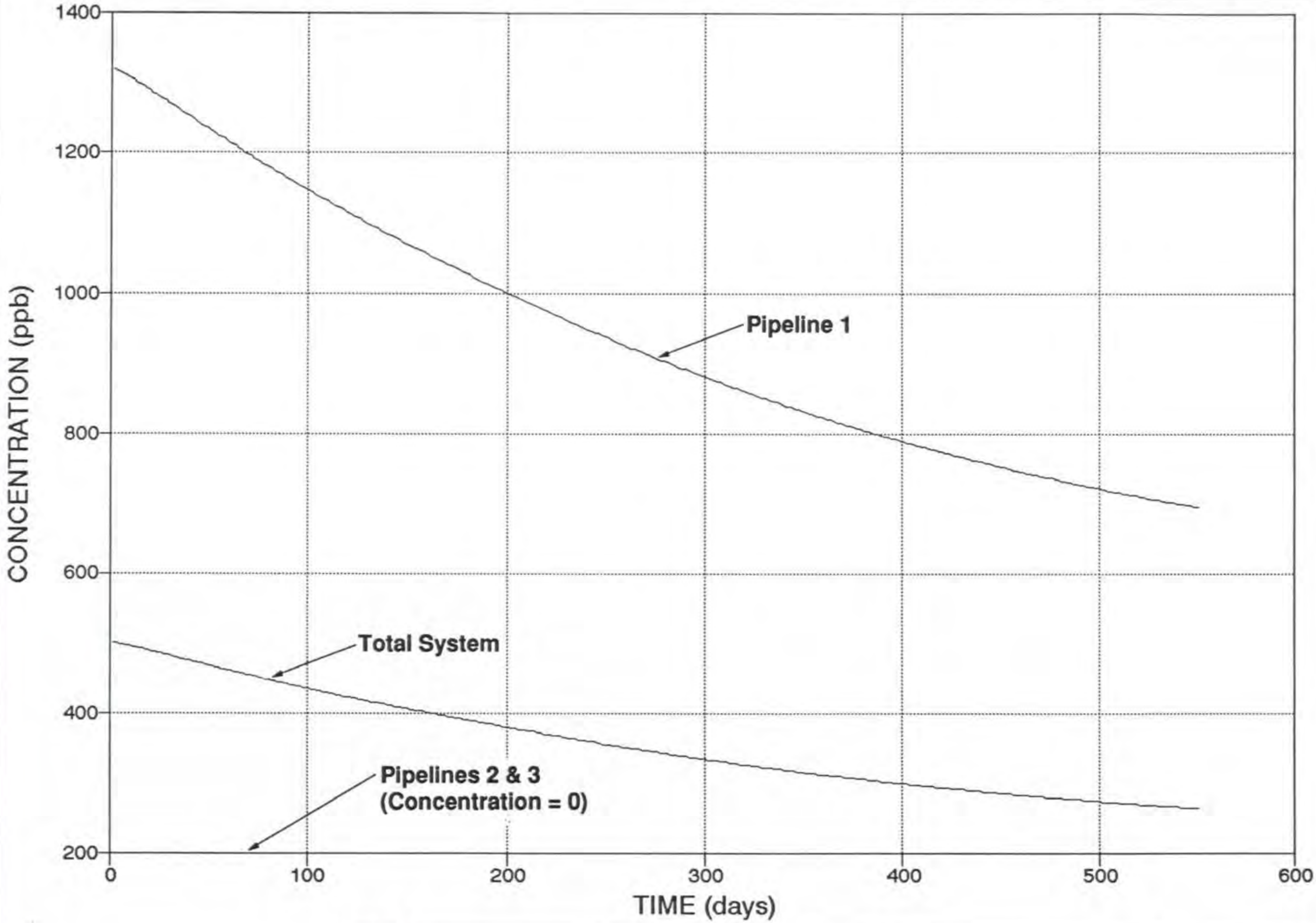
Upper Aquifers
TCA Distribution

Figure C-4



Time vs. Concentration Simulation
TCA

Figure C-5



Time vs. Concentration Simulation
Methylene Chloride

Figure C-6

TABLE C-1

ESTIMATED PEAK CONCENTRATIONS
FOR PHASE II EXTRACTION WELLS

Well Designation	Flow Model	Assumed Flow Rate[a] (gpm)	Estimated Peak Concentration (ppb)		Pipeline Designation
			MC	TCA	
South System	Upper Sand/Gravel Aquifer				
CP-S1		55	N/A[b]	180	3
CP-S3		50	N/A	190	3
CP-S4		50	N/A	350	3
CP-S5		50	N/A	620	3
CP-S6		50	N/A	620	3
West System	Lower Sand/Gravel Aquifer				
CP-W1		100	0	380	2
CP-W2		100	1,300	2,500	1
CP-W3		100	460	2,800	1
CP-W4		100	0	330	2
East System	Lower Sand/Gravel Aquifer				
CP-E1		60	3,400	3,800	1
CP-E2[c]		5	--	--	3
CP-E3		50	540	1,700	1
CP-E4		50	0	310	3

(a) Estimated flow rates from capture zone analyses in Appendix B.

(b) N/A = not applicable.

(c) Outside of model boundary, peak concentrations not estimated.

TABLE C-2

COMBINED PIPELINE AND TOTAL SYSTEM
ESTIMATED CONCENTRATIONS FOR TCA AND MC

Pipeline/System Designation	Estimated Flow Rate (gpm)	TCA	MC
Pipeline 1	310	2,500	1,300
Pipeline 2	200	290	0
Pipeline 3	310	250	0
Total System[a]	820	1,100	500

(a) Combined flow for pipelines 1, 2, and 3.

APPENDIX D

Total Dynamic Head and Brake Horsepower Calculations

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDIX D

ESTIMATED TOTAL DYNAMIC HEAD AND BRAKE HORSEPOWER

INTRODUCTION

The purpose of this Appendix is to outline the procedures used to estimate total dynamic head (TDH) and brake horsepower (BHP). TDH and BHP are design parameters required for selection of the submersible pumps that will be used for the Phase II Colbert Landfill Project (Project) groundwater extraction system.

TOTAL DYNAMIC HEAD

TDH (in feet) is the summation of the elevation, velocity, and friction head losses. Velocity head losses are considered negligible, and were not calculated for this Project. The elevation and friction head losses used to calculate TDH include:

$$\text{Elevation Head} = SWL + ELV + TL$$

where

SWL = lift from static water level (ft)

ELV = elevation change from well head to stripping tower base (ft)

TL = lift to top of stripping tower (ft)

$$\text{Friction Head} = F_{pc} + F_{pipe} + F_{elb} + F_{val}$$

where

F_{pc} = friction loss in pump column (ft)

F_{pipe} = friction loss in pipeline from well head to stripping tower (ft)

F_{elb} = friction loss for elbows (ft)

F_{val} = friction loss for valves (ft)

$$TDH = \text{Elevation Head} + \text{Friction Head}$$

The Hazen-Williams equation for flow through a rigid pipe was used to calculate the friction head losses:

$$f = 0.2083 \left(\frac{100}{C}\right)^{1.852} x \ \frac{Q^{1.852}}{d^{4.8655}}$$

where:

f	=	friction head loss (ft head loss per 100 ft of pipe)
d	=	pipeline diameter (inches)
Q	=	flow rate (gpm)
C	=	roughness coefficient for pipe (C = 130 for thermoplastic pipe).

Pipeline Diameters and Design Flows

Extraction system pipeline design diameters and flow rates are presented in the Preliminary Treatment and Discharge Plan (Landau Associates 1992). Maximum design flow rates (including capacity for system expansion) and maximum well capacity were used for pipeline sizing. However, TDH calculations are based on anticipated Phase II flow rates, which are significantly less than the maximum design flow rates. Phase II extraction well locations, pipeline routing, and pipeline diameters are shown on Figure D-1 and anticipated Phase II flow rates are provided in Table D-1.

A separate calculation of friction head loss must be made for each pipeline segment with a different diameter or flow rate. Thus, the pipeline must be subdivided into segments of equal flow and diameter. Pipeline segments for TDH calculations are shown on Figure D-2. Pipeline segment design flows and design diameters are presented in Table D-2.

Elevation Head Loss

Elevation head loss includes the lift from the static water level in the well to the ground surface, the change in elevation between the well and the stripping tower, and the lift to the top of the stripping tower. The static water level lift and elevation change were estimated based on Phase I data. The stripping tower lift is estimated to be 70 ft based on preliminary stripping tower design. Estimated values for static water level lift, elevation change and stripping tower lift are provided in Table D-1.

Friction Head Loss

Friction head losses include losses associated with flow through the pump column, elbows, valves, and pipeline segments. The calculations and assumptions used to estimate the friction losses are described in the following subsections.

Friction Loss in Pump Column

For calculating the friction losses in pump columns (F_{pc}) a 3-inch diameter was assumed for each pumping well, except for CP-E2, where a 1.25-inch diameter pump column was assumed. The size of the pump column is based on manufacturer recommendations for the anticipated discharge rate. The length of the pump column is equivalent to the anticipated depth below ground surface that the pump will be set, and is assumed to be the top of screen depth described in Section 3.3 of the main body of this Plan. A pipe roughness coefficient (C) of 100 was used, assuming galvanized steel pipe will be used for pump columns. Estimated F_{pc} values for Phase II extraction wells are presented in Table D-1.

Friction Loss in Valves and Fittings

Friction loss for valves (F_{val}) and fittings (F_{elb}) was calculated by converting the fixture friction loss to equivalent pipeline length, and then calculating friction loss for the equivalent pipeline length). A total of six elbows was assumed for each pumping well. The size of the equivalent pipeline length is based on the smallest pipeline diameter associated with the pumping well. Three valves were assumed for each pumping well: 1) check-ball valve, 2) globe valve, and 3) diaphragm valve. A 3-inch pipe diameter was also assumed for valve equivalent pipeline length calculations, except a 2.0-inch diameter was assumed for Well CP-E2. Estimated F_{elb} and F_{val} values for Phase II extraction wells are presented in Table D-1.

Friction Loss in Pipelines

The extraction well discharge rates used to calculate friction loss in pipelines (F_{pipe}) is based on the anticipated discharge rate, as presented in Table D-1. Figure D-2 shows the pipeline segments with reference nodes, and Table D-2 summarizes discharge rates, diameters, and friction head losses for each pipeline segment. The pipeline friction head loss for a given well is the summation of the individual friction head losses for pipeline segments (per Figure D-1) from the well head to the stripping tower. Estimated F_{pipe} values are presented in Table D-1.

Design TDH

The estimated TDH for Phase II extraction wells is provided in Table D-1. However, the estimated TDH is based on limited head-loss information for fittings, valves, and other head loss features associated with the treatment facility. As a result, a 25 percent factor of safety will be applied to the estimated TDH values to account for unidentified head loss components. Design TDH values are provided in Table D-1. Following is an example TDH calculation for pumping well CP-W3:

- Q = discharge = 130 gpm
- SWL = static water lift = 190 ft
- TL = stripping tower lift = 70 ft
- ELV = elevation change = 5.2 ft

(1) Elevation Head = SWL + TL + ELV

$$190 \text{ ft} + 70 \text{ ft} + 5.2 \text{ ft} = 265 \text{ ft}$$

(2) F_{pc} = (friction loss in pump column) (ft):

$$f = 0.2083 \left(\frac{100}{C}\right)^{1.852} x \frac{Q^{1.852}}{d^{4.8655}}$$

where:

f = friction head loss (ft head loss per 100 ft of pipe)

C = constant for inside roughness of pipe = 100 (galvanized pipe)

Q = discharge = 130 gpm

d = inside diameter of pipe, in inches = 3 inches

L = length of pump column = 280 ft

Thus:

$$f = 0.2083 \left(\frac{100}{100}\right)^{1.852} x \frac{(130\ gpm)^{1.852}}{(3.0\ inches)^{4.8655}}$$

$$f = \frac{8.17\ ft}{100\ ft}$$

$$F_{pc} = (f)(L)$$

$$F_{pc} = \frac{8.17\ ft}{100\ ft}\ x\ (280)$$

$$F_{pc} = 22.9\ ft$$

(3) F_{pipe} = (friction loss in pipeline) (ft):

Same equations as (2), where:

Q = 130 gpm
L_{p-o} = pipeline length = 350 ft
L_{o-1} = pipeline length = 600 ft
d_{p-o} = 6 inches
d_{o-1} = 8 inches
C = 130 (PVC pipe)

$$f_{p-o} = 0.2083 \left(\frac{100}{130}\right)^{1.852} \frac{(130)^{1.852}}{(6)^{4.8655}}$$

$$f_{p-o} = \frac{0.17\ ft}{100\ ft}$$

$$F_{\substack{pipe\\p-o}} = \left(\frac{0.17\ ft}{100\ ft}\right) (350\ ft)$$

$$F_{\substack{pipe\\p-o}} = 0.6\ ft$$

$$f_{o-l} = \frac{0.35\ ft}{100\ ft}$$

$$F_{\substack{pipe\\o-l}} = \left(\frac{0.35\ ft}{100\ ft}\right) (600\ ft)$$

$$F_{\substack{pipe\\o-l}} = 2.1\ ft$$

$$F_{\substack{pipe\ total\\p-l}} = 0.6 + 2.1 = 2.7\ ft$$

(4) F_{elb} = (friction loss for elbows) (ft):

Assume six 6-inch diameter elbows
6-inch diameter elbow = 18 ft equivalent pipeline length
Q = 130 gpm
C = 130

L_{eql} = 18 *ft* x 6 = 108 *ft* *equivalent pipeline length*

Friction loss [same as equation (2)]:

$$f = 0.2083\left(\frac{100}{130}\right)^{1.852} x \frac{(130\ gpm)^{1.852}}{(6.0\ inches)^{4.865}}$$

$$f = \frac{0.173\ ft}{100\ ft}$$

$$F_{elb} = \left(\frac{0.173\ ft}{100\ ft}\right)(108\ ft)$$

$$F_{elb} = 0.2\ ft$$

(5) F_{val} = (friction loss for valves) (ft):
Assumes 3-inch diameter pipe, where:

One check-ball valve; L_{eql} pipe = 70 ft

One globe valve; L_{eql} = 6 ft

One diaphragm valve; L_{eql} = 2.6 ft

Q = 130 gpm

C = 130

$$L_{eql}\ (total) = 70\ ft + 6\ ft + 2.6\ ft = 78.6\ ft$$

Friction loss (f) for a 3-inch diameter pipeline [same equation as (2)]:

$$f = 0.2083 \left(\frac{100}{130}\right)^{1.852} x \ \frac{(130\ gpm)^{1.852}}{(3.0\ inches)^{4.8655}}$$

$$f = \frac{5.03\ ft}{100\ ft}$$

$$F_{val} = \left(\frac{5.03\ ft}{100\ ft}\right)(78.6 ft) = 4.0\ ft$$

(6)

$$\textit{Total Friction Head} = F_{pc} + F_{pipe} + F_{elb} + F_{valv}$$
$$= 22.9\ ft + 2.70\ ft + 0.2\ ft + 4.0\ ft = 30\ ft$$

(10)

$$\textit{Total Dynamic Head} = (\textit{Total Friction Head}) + (\textit{Elevation Head})$$
$$= 30\ ft + 265\ ft = 295\ ft$$

(11)

$$\textit{Design Total Dynamic Head} = TDH\ x\ 1.25$$
$$= 295\ ft\ x\ 1.25 = 369\ ft$$

$$\boxed{\textit{Design TDH} = 369\ ft}$$

BRAKE HORSEPOWER

Water horsepower (WHP) is defined as the energy, in horsepower, required to pump water against a given head without taking into account pump efficiency or friction losses (Driscoll 1986). Water horsepower is calculated by the following equation:

$$WHP = \frac{Q \times wt\ H_2O \times TDH \times sp.\ gr.}{33{,}000}$$

or

$$WHP = \frac{Q \times TDH}{3{,}960}$$

where:

Q	=	discharge (gpm)
wt H_2O	=	weight of 1 gallon of water (8.33 lb)
TDH	=	total dynamic head (ft)
sp. gr.	=	specific gravity (water = 1)
33,000	=	conversion factor

Because submersible pumps are not 100 percent efficient, greater horsepower is required to drive the pump than calculated by the WHP equation (Driscoll 1986). Brake horsepower (BHP) takes into account the pump efficiency and is calculated by the following equation:

$$BHP = \frac{WHP}{pump\ efficiency}$$

or:

$$BHP = \frac{Q \times TDH}{3{,}960 \times pump\ efficiency}$$

Submersible pump efficiency varies, but normally is 75 percent or less. For the purpose of estimating brake horsepower requirements for this Project, a pump efficiency of 70 percent was assumed. Brake horsepower requirements for Phase II extraction wells are provided in Table D-1. The following is an example calculation for Extraction Well CP-W3:

Q	=	130 gpm
Design TDH	=	369 ft
Pump Efficiency	=	70 percent (assumed)

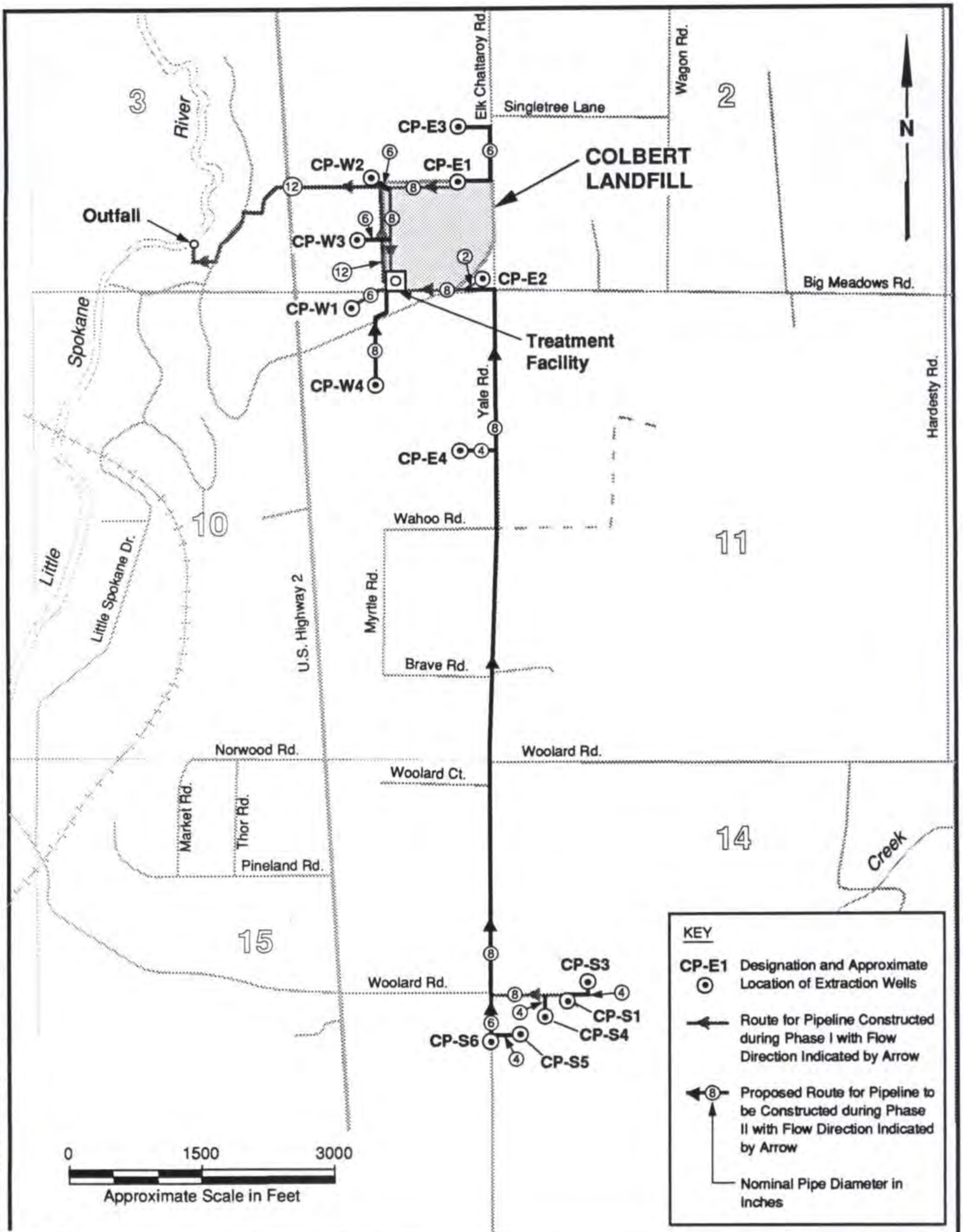
$$BHP = \frac{(130\ gpm)(369\ ft)}{(3{,}960)(0.70)}$$

$$\boxed{BHP_{CP-W3} = 17\ horsepower}$$

REFERENCES

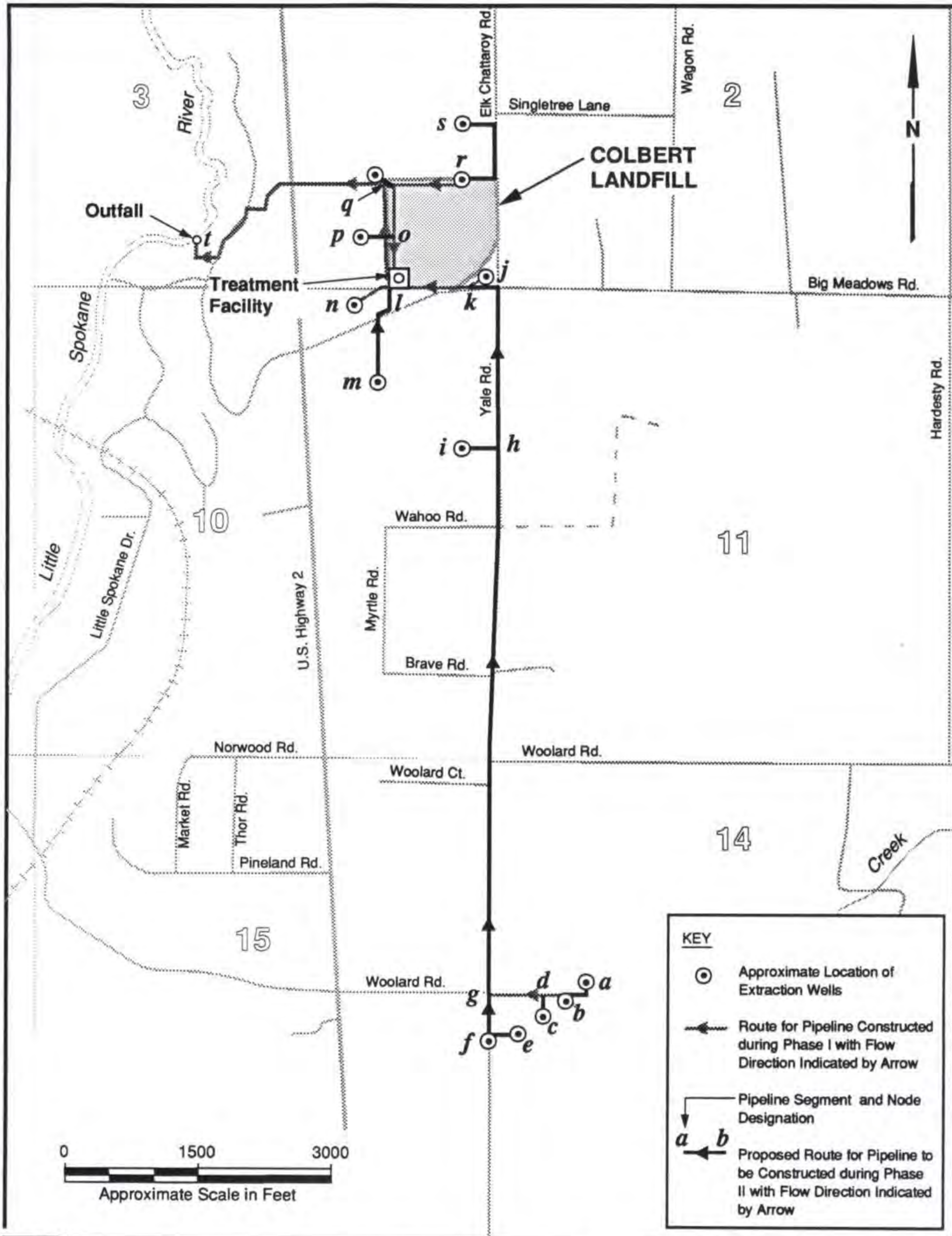
Driscoll, F.G. 1986. Groundwater and Wells: Johnson Division, St. Paul, MN.

Landau Associates, Inc. 1992. Preliminary Treatment and Discharge Plan. Phase II Remedial Design/Remedial Action. Colbert Landfill. Spokane, WA. 28 March 1992.



Phase II Pipeline Routing

Figure D-1



Phase II Pipeline Design Segments

Figure D-2

124001.72 Spokane Co./Colbert Landfill/ RD/RA Phase II / Final Extraction Well Plan - Appendix D 8/92

TABLE D-1

ESTIMATED TDH AND BHP[a]

Well ID	Q (gpm)	SWL (ft)	ELV (ft)	TL (ft)	TEH (ft)	F_{pc} (ft)	F_{pipe} (ft)	F_{elb} (ft)	F_{val} (ft)	TFH (ft)	Estimated TDH (ft)	Design TDH (ft)	BHP
West System													
CP-W1	130	190	4.2	70	264	22.9	0.6	0.2	4.0	28	292	365	17
CP-W2	130	190	6.2	70	266	22.9	3.4	0.2	4.0	30	297	371	17
CP-W3	130	190	5.2	70	265	22.9	2.7	0.2	4.0	30	295	369	17
CP-W4	130	190	-0.7	70	259	22.9	0.5	0.2	4.0	28	287	359	17
South System													
CP-S1	60	90	7.8	70	168	1.8	19.6	0.3	0.9	23	190	238	5
CP-S3	50	90	7.5	70	168	1.3	20.4	0.2	0.7	23	190	238	4
CP-S4	50	90	3.5	70	164	1.3	19.9	0.2	0.7	22	186	232	4
CP-S5	60	90	0.3	70	160	1.8	20.8	0.3	0.9	24	184	230	5
CP-S6	60	90	-1.5	70	159	1.8	19.8	0.3	0.9	23	181	227	5
East System													
CP-E1	80	200	-6.4	70	264	7.6	3.6	0.1	1.6	13	277	346	10
CP-E2	5	175	-10.7	70	234	2.5	2.0	0.1	0.1	5	239	299	0.5
CP-E3	65	200	-10.1	70	260	5.2	4.3	0.1	1.1	11	271	338	8
CP-E4	65	190	-6.8	70	253	5.2	9.4	0.4	1.1	16	269	337	8

[a] The following abreviations are used in this table:

Q = anticipated discharge rate
SWL = lift from static water level
TL = lift at stripping tower
ELV = change in elevation between well head and stripping tower
TEH = Total Elevation Head = SWL + TL + ELV
F_{pc} = friction loss in pump column
F_{pipe} = friction loss in pipeline from pumping well to stripping tower
F_{elb} = friction loss for all elbows in line; 6 elbows assumed
F_{val} = friction loss in valves (includes check-ball valve, globe valve and diaphragm valve)
TFH = Total Friction Head = $F_{pc} + F_{pipe} + F_{elb} + F_{val}$
TDH = Total Dynamic Head = (Total Elevation Head) + (Total Friction Head)
Design TDH = TDH x 1.25
BHP = Brake Horsepower

TABLE D-2

ESTIMATED FRICTION LOSS IN PIPELINE SEGMENTS

Pipeline Segment	Combined Discharge (gpm)	Pipeline Design Diameter (inches)	Pipeline Length (ft)	Friction Loss per 100 ft (f/100 ft)	Friction Loss per Pipeline Segment (F_{pipe})[a]
a-b	50	4	400	0.21	0.85
b[b][c]	60	4	25	0.30	0.07
b-d[c]	110	8	300	0.03	0.09
c-d	50	4	250	0.21	0.53
d-g[c]	160	8	650	0.06	0.41
e-f	60	4	350	0.30	1.04
f-g	120	6	500	0.15	0.74
g-h	280	8	6350	0.18	11.18
i-h	65	4	450	0.34	1.55
h-k	345	8	2300	0.26	5.96
k-l[c]	350	8	700	0.27	1.86
j-k[c]	5	2	120	0.09	0.10
m-l	130	8	1200	0.04	0.51
n-l[c]	130	6	415	0.17	0.65
s-r	65	6	1400	0.05	0.67
r-q[c]	145	8	850	0.05	0.44
q[b]	130	6	125	0.17	0.22
q-o[c]	275	8	650	0.17	1.11
p-o	130	6	350	0.17	0.60
o-l[c]	405	8	600	0.35	2.09

(a) (Pipe Length) (Friction Loss Per 100 ft)/100

(b) Pipeline segment from well to common pipeline.

(c) Pipeline constructed during Phase I.